NASA Reference Publication 1067

Aerial Color Infrared Photography: Applications in Citriculture

Carlos H. Blazquez and Frank W. Horn, Jr.

NOVEMBER 1980

NASA

NASA Reference Publication 1067

Aerial Color Infrared Photography: Applications in Citriculture

Carlos H. Blazquez
University of Florida
Lake Alfred, Florida

Frank W. Horn, Jr.
NASA John F. Kennedy Space Center
John F. Kennedy Space Center, Florida

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1980

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

PREFACE

A major goal of NASA's Applications Program is the use of remote sensing technology in the management of earth resources. The Applications Project Branch at the John F. Kennedy Space Center (KSC) has worked closely for several years with the Florida agricultural community to accomplish this goal. Such activities inevitably led to close cooperation with the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida, which has the responsibility within the state for agricultural research and extension services. This project for the application of Aerial Color Infrared (ACIR) photography to citriculture is a result of this cooperation.

Although the use of CIR photography for vegetation analysis has been recognized for years, with one of the earliest experiments being in Florida citrus, no systematic use of this technique has ever been implemented on an operational basis. Further investigation of this paradox revealed a sizeable gap in knowledge and communication between the citrus growers who could profit and the aerial photographers who could provide it. In other words, the photographic products and services normally provided by aerial photographers has not been used by growers to extract the needed information. Successful bridging of this gap by NASA and IFAS would offer potentially large benefits to growers at reasonable costs.

NASA and IFAS adopted a three-phase project to close this information gap. The first phase was an experiment to define the optimum photographic specifications and operational parameters of such a system. The second phase involved several major growers and commercial aerial photographers refining and demonstrating the operational use of the techniques identified in phase one. The third phase is the transfer of this information to the grower community and includes the publication of this handbook and other instructional material, and the conduct of conferences, workshops, and other training techniques.

The results of the experiments conducted in phase one to determine the optimum photographic system will be published separately in the near future. This handbook addresses only the system considered most appropriate for the intended applications. It contains information sufficient in detail to guide the grower not experienced in aerial photography and photo interpretation in the adoption of a system for their own grove, regardless of size or physical configuration.

As the project developed it became apparent that application to very large groves would be greatly facilitated by the use of computers. Therefore, the system is designed for computerization and the use of computers for input, output, and data compilation and is discussed as appropriate throughout the handbook.

CONTENTS

Section | Page

PREFACE iii
TABLE OF CONTENTS v
LIST OF ILLUSTRATIONS vii
TABLES viii
INTRODUCTION 1
- Purpose 1
- Background 1
- Uses 2
- Users 2
- Sequential Steps for ACIMS 3

MISSION PLANNING 4
- Mapping 4
  - Grove Registration 4
  - Flight Line Preparation 6
  - Forward and Side Lap Determination 6
  - Photographic Frame Estimation 6
- Photographic Requirements 7
  - Camera Requirements 7
  - Film Requirements and Properties 9
  - Light Limitations 9
  - Scale of Photography 11
- Horticultural Restrictions 19
  - Best Season for Photography 19
  - Planting Distance 19
  - Canopy Density 20
  - Varietal Differences 20
  - Background effects 20
- Photographic Product Requirements 24
  - Enlargements 24
  - Optional Contact Prints 24
  - High Altitude Photography 24
- Writing of Contracts 24

MISSION IMPLEMENTATION 29
- Aerial photographic Mission 29
  - Weather Variables 29
  - Mission Accomplished Same Day 29
  - Flight Logs 29
  - Film Identification (Frame and Counter Numbers) 29
- Acceptance of Aerial Photography 30
- Grower Film Labeling and Frame Registration 30
- Film Cutting 31
  - Page Protector Labeling 31
  - Frame Registration after Cutting 31

PHOTO INTERPRETATION 32
- Choice of Equipment 32
  - Light Table 32
  - Magnifying Lenses 32
  - Dissecting Stereoscopic Microscopes 35

CONTENTS (con't)

Section Page

35 MM Copying Cameras 35
Microfiche Viewers 35
Thin Glass Plates 35
Expendable Items 35
Other Items 36
Extraction of Information (Data Interpretation) 36
Analysis of Vegetation 37
Soil Differences 48
Effects of Water 48
Effects of Weather 48
Mechanical Damage 53
Seasonal Growth Effects 53
Ground Verification Techniques 53
DATA RECORDING AND PROCESSING 56
Grove Grid/Cell Design 56
Manual Recording Systems 56
Overlay Processing 56
Window Overlay System 58
Computer Systems 58
Automated Photo Interpretation/Analysis 58
DATA PRODUCTS 61
Grove Status Reports 61
Computer Printouts 63
APPENDIX 66
Aerial Photography 66
Remote Sensing 67
Electromagnetic Radiation 69
Sensor Systems 71
Types of Platforms 72
GLOSSARY 75
REFERENCES 80

ILLUSTRATIONS

		Page
Figure 1.	Photographic Frame Estimation Template for 4000 ft. Altitude	8
Figure 2.	Comparison of Area Coverage with 6-inch and 12-inch Lenses	10
Figure 3.	Sun Angle Variability	12
Figure 4.	Sun Spot Photograph	13
Figure 5.	Diagram of the Location of the Sun Spot and Aircraft Shadow	14
Figure 6.	Aerial CIR Photograph of a Lake County Grove from 4000 feet	16
Figure 7.	Aerial CIR Photograph of a Lake County Grove from 6000 feet	17
Figure 8.	Aerial CIR Print of a Lake County Grove from 8000 feet	18
Figure 9.	Schematic Diagram for Measuring or Estimating Tree Canopy Size	21
Figure 10.	Changes in Soil Types	22
Figure 11.	Summer Photograph of a Lake County Grove Showing Grass and Shadows	23
Figure 12.	Sprinkler System in a Grove in Polk County	25
Figure 13.	Effect of Rainbird Down the Row	26
Figure 14.	Pipe Irrigation in a Grove in Polk County	27
Figure 15.	Comparison of Photo Interpretation and Ground Verification – Single Cell	28
Figure 16.	Large and Small Photo Interpretation Tables	33
Figure 17.	Hand Lenses	34
Figure 18.	Color Chart for Use as a Color Calibration	38
Figure 19.	Calibration Photograph (Grapefruit and Valencia Trees)	39
Figure 20.	Enlargements of Tree Conditions (Ø, 1, 2, 3, 4)	41
Figure 21.	Enlargements of Tract-Type Grove Showing Vines, Grasses, and Weeds	42
Figure 22.	Fort Pierce Agricultural Research Center (ARC) Sooty Mold Plot and Enlargement	43
Figure 23.	An Aerial CIR Photograph of Kennedy Space Center (KSC) Showing Sooty Mold and Clouds	44
Figure 24.	Replanted Area Due to Nematode Damage	46
Figure 25.	Enlargement of Tree Sizes	47
Figure 26.	Winter Photography of a Grove in Polk County with Avocado Enlargement	49
Figure 27.	Spring Photography of a Grove in Polk County with Avocado Enlargement	50
Figure 28.	Summer Photography of a Grove with Avocado Enlargement	51
Figure 29.	A St. Lucie County Grove with Muck Pocket Showing Healthy Trees	52
Figure 30.	Irrigation Effects and Mechanical Damage from Hedging and Topping	54
Figure 31.	Comparative Observations Work Sheet	55
Figure 32.	Schematic Diagram of a Grid/Cell System Adaptable to Tract or Bed Type of Planting	57
Figure 33.	A Polk County Grove with a Blue Cell Overlay	59
Figure 34.	A Comparison of Hand Written and Computer Symbols	60

ILLUSTRATIONS (con't)

Page

Figure 35. Hand Processing Work Form 62
Figure 36. Examples of Computer Printouts of Tree Conditions 64
Figure 37. Example of Crop Production Forecast 65
Figure A-1. Sensitivity of Color Infrared Film and Wavelengths 68
Figure A-2. Sensitivity of Normal Ektachrome Color Film and Wavelengths 68
Figure A-3. A Schematic Diagram of the Electromagnetic Spectrum 70
Figure A-4. Upper Limits of Sensitivity of Photographic and Electronic Sensors 73

TABLES

Table 1. Sources of Photography and Types of Photographs Available for Florida 5
Table 2. Acreage Gained per Altitude Increase 15
Table 3. Total Acreage (Hectares) per Altitude Change 19

INTRODUCTION

In the management of citrus groves, growers or managers are required to make decisions based on observations and findings during periodic field inspections. Most of these observations and findings are related to total inventory and unit costs (fertilization, replacements, production, irrigation, etc.) per acre. In recent years the spiraling costs of production, the increasing restrictions on the use of fungicides and insecticides, and increasing energy costs, have complicated considerably the options that managers have and emphasizes the need to minimize waste and reduce costs. Thus, there is a strong incentive for a faster, more accurate, and more cost-effective way to inspect and monitor citrus groves. Aerial photography with CIR film is a surveillance system that meets most of the requirements for grove inspections, and may be an alternative to field inspections.

PURPOSE

This handbook provides the Florida citrus industry with a guide for the use of ACIR photography in the management of citrus groves. It contains necessary instructions in the acquisition and analysis of data as well as requirements and specifications of photographic systems and equipment. It addresses only those techniques most appropriate for Florida applications and does not discuss alternate approaches or selection criterion.

BACKGROUND

During experimentation with electronic surveillance systems for citrus groves, it was determined that the Florida agricultural community was generally unfamiliar with, and had little interest in, using aerial photography to solve grove management problems. This was somewhat surprising as it had been assumed that everyone was completely knowledgeable of the benefits of aerial photography. It was also apparent that the aerial photographic companies were not familiar with agricultural remote sensing problems and the advantages of using CIR photography.

The KSC/IFAS project was an experiment, with grower assisted follow-up, using vertical CIR photography that resulted in the development of an Aerial Color Infrared Management System (ACIMS) which is described in detail in this handbook. While it is recognized that other approaches to this subject exist, the selected photographic techniques, horticultural restrictions, and photo interpretation methods used in this project were considered by the authors as the optimum approach.

A more detailed historical background of ACIR film, its development, and adaptation to agriculture is contained in the Appendix.

USES

ACIMS can be extremely useful to a grove manager, owner, or caretaker because it will provide an accurate record which can be used to determine the total numbers of:

1. Trees in production
2. Trees of different sizes
3. Healthy trees
4. Replacement trees needed for next year
5. Replacement trees needed two years from date of photograph
6. Missing trees
7. Dead trees.

In addition, the photography is useful to locate problems such as:

1. Wet and dry areas
2. Weeds
3. Grassy areas
4. Noxious trees
5. Nematode damaged areas
6. Malfunctioning sprinklers and broken irrigation ditches/pipes.

The CIR photographs also serve as a record to determine production trends and patterns of change. It permits a grower to place a nursery order for a more accurate number of trees before the normal time with knowledge based on actual tree counts, rather than estimates.

USERS

The combination of aerial surveillance, Kodak's Aerochrome 2443 CIR film, and a registration system for locating trees were integrated into a resource management system for monitoring citrus grove changes. ACIMS was developed as a flexible system for use by individuals concerned with investment, production, and maintenance of citrus groves. Some of the advantages accruing from the applications of ACIMS follows:

1. The owner of a citrus grove, his production manager, his field manager, or in actuality, just about anyone involved in tree maintenance can use information gained from an ACIR system.

2. Grove care-taking companies can obtain a more accurate record on which to base their costs and profit margin if ACIR photography is utilized.

3. Large nurseries can obtain ACIR photographs of their customer's groves and determine fairly accurately what number of trees would be required by their customers.

4. Growers can accurately determine actual grove acreage in production and also non-productive areas due to low, wet, or poor soil areas.

5. Growers, desiring to purchase new or additional groves, will be able to determine the current condition of trees in the grove, and identify potential problem areas. This would not be possible without the use of ACIMS.

6. Banks and mortgage companies can determine more accurately the potential assets and liabilities involved in the purchase of groves.

7. County Tax Appraisers can have a better system for more accurately evaluating the losses of production in a grove due to pests, diseases, mechanical, or weather factors.

8. Growers with considerable tree losses can document the number of trees in production and the Tax Appraisers can reduce their grove taxes based on this information.

SEQUENTIAL STEPS FOR ACIMS

This portion was prepared to clearly outline the specific sequential tasks to be followed in carrying out the photographic mission and obtain the desired results and data products.

1. Mission Planning: Grower-Aerial Photographer Sessions
2. Photographic Requirements: Camera, Film, Altitude, Cloud Cover
3. Horticultural Restrictions Affecting ACIR Photography
4. Photographic Product Requirements
5. Writing of Contract/Letter of Agreement
6. Aerial Photographic Mission
7. Acceptance of Aerial Photography: Compliance with Contract Requirements
8. Grower Film Labeling and Frame Registration

9. Film Cutting

10. Photo Interpretation/Data Analysis

11. Data Recording and Processing

12. Data Products.

MISSION PLANNING

Planning of an aerial photographic mission requires coordination and cooperation between the individuals requiring the mission and those performing it. It is essential that all potential problem areas be discussed and that acceptable compromises be agreed upon prior to writing a contract for the photographic mission. The following paragraphs identify and discuss those elements of mission planning necessary for identifying the photographic data to be collected.

MAPPING

In planning a photographic mission it is necessary to prepare a set of maps to correctly identify the area to be photographed. Planning sessions between growers and aerial photographers are extremely desirable in order to eliminate areas of misunderstanding. Growers should bring to the planning session the following:

1. A baseline data map of the grove combining previous grove information available from planting maps, replacement orders, or nursery purchases. It is mandatory to incorporate the best or most used system of classification identifying the grove, block, division, row, and tree number into the baseline data map used in delineating the desired areas of an aerial photograph.

2. Background aerial photography (Table 1) is necessary to delineate the scope of the mission and is used in selecting flight lines and determining potential horticultural restrictions. These restrictions include canopy density, light reflectance, grove natural borders, planting distances, and acreages.

Grove Registration

The term grove registration describes the geographical location of a grove (latitude and longitude) as well as the legal description (county, township, range, and section) used by the U.S. Geological Survey and Tax Assessor's Office. Grove registration is necessary to obtain all existing or previously taken aerial photographs or surveys of the grove. The sources and types of aerial photography available are shown in Table 1. The principal and easiest sources among these are the County Tax Assessor and Livestock and Crop Reporting Service.

County Tax Assessor blue-line maps can be obtained at the County Seat and usually are at a scale of 1 in. = 400 ft (2.5 cm = 123 m) or 1 in. = 200 ft (2.5 cm = 61 m). These blue-line maps have a scale large enough to ascertain the planting distance of the trees, and determine if canopy density will be a factor in exposing the film.

The Livestock and Crop Reporting Service has been photographing Florida's citrus groves since 1965 and can provide small scale photography, 1 in. = 30,000 ft (2.5 cm = 9144 m), or enlargements up to 1 in. = 670 ft. (2.5 cm = 204 m). These black and white (B&W) photographs are excellent for orientation and location of flight lines. These photographs are not useful for developing detailed information on the grove.

In areas where the above sources are not available, other photography (Table 1) may be used. Another option would be an exploratory high-altitude overflight that would produce either or both of the previously listed scale photography.

Table 1. Sources of Photography and Types of Photographs Available for Florida

Agency	Addresses	Information Available
Florida Livestock and Crop Reporting Service (CRS)	1222 Woodward Street Orlando, Florida 32803 305/420-6023	Contact prints B&W enlargements (on paper and/or mylar)
USDA Agricultural Stabilization and Conservation Service (ASCS)	Aerial Photography Field Ofs. 2222 West, 2300 South P. O. Box 30010 Salt Lake City, Utah 84130 801/524-5856	B&W contact and paper enlargements
U. S. Department of the Interior Geological Survey	National Cartographic Information Center U. S. Geological Survey 507 National Center Reston, Virginia 22092 703/860-6045	B&W contact prints and enlargements
County Tax Assessor	Local County Seat	Blue-line Diazo maps of citrus groves and property in county
Agricultural Research and Education Center, Lake Alfred, IFAS, University of Florida	P. O. Box 1088 Lake Alfred, Florida 33850 813/956-1151	Order blue-line Diazo maps of citrus groves
Fla. Dept. of Transportation Topographic Engineer	Hayden Burns Building 605 Suwannee Street Tallahassee, Florida 32304 904/488-8911	County photography at desired scale--B&W contacts and paper or mylar enlargements

Flight Line Preparation

Flight lines are usually drawn by the aerial photographer; however, considerable misunderstandings can be avoided if the grower, manager, or field supervisor of the grove cooperate in flight line preparation.

The shape of the grove will probably determine the direction of the flight line, and since fewer lines means fewer turns and reduced photographic costs, it is best to fly in the direction of the rows. This is particularly important in bed-type planting, where flying across the beds makes registration much more difficult, increasing labor costs of photo interpretation.

Forward and Side Lap Determination

Overlap is the amount of duplicate coverage of an area in other photographs and is usually expressed in percentages. Forward lap is done for the alignment of successive frames, and for stereoscopic viewing in the areas of overlap. The standard forward lap is 60 percent. Side lap is the amount of duplicate coverage of an area in an adjacent flight line and is also expressed in percentages. It is done for parallel alignment of flight lines in an area where more than one flight line is required to photograph a grove area. The greater percentage of side lap will result in an increased number of flight lines. Preferred side lap is normally 30 percent or less, but not less than 20 percent.

Photographic Frame Estimation

The most simple technique employed to estimate the number of frames required is to make a template of the size of the frame (at the proper scale) indicating the area to be covered and count the number of frames per flight line on a map for the forward and side laps necessary to cover the desired area (Figure 1 and template).

If a template is not used the number of frames required can be calculated as follows: assuming that the photograph was taken with a 12-in. (30-cm) focal length lens at 4000 ft (1220 m) altitude, the frame has a scale of 1 ft = 4000 ft (30 cm = 1220 m), a 1-ft negative would cover 4000 ft on the ground. However; the actual size of the frame is 9 in. x 9 in. (23 cm x 23 cm), which means that the frame is only 0.75 ft x 0.75 ft (0.23 m x 0.23 m), and thus would cover only an area 3000 ft x 3000 ft (914 m x 914 m) on the ground. If a 60-percent overlap is required in the photograph, a 40-percent advance of the film is needed per frame. Two additional photographs must be taken at the beginning and the end of each flight line in order to obtain the necessary 60 percent overlap on the first and last photograph. This means that the amount of ground gained forward (GGF) is determined by the equation:

Percent forward lap = percentage advance of film x size of frame x ground area = GGF

<u>Example</u>

60 percent forward lap = 40 percent x 0.75 ft x 4000 ft = 1200 ft

If a 30-percent side overlap is required in the photograph, double photography will be required on 30 percent, which means that the width of the frame is reduced to 70 percent, and the number of flight lines must be calculated on this reduced width. Thus, to determine how much side lap will be covered by the width of the frame, calculate the following for ground gained side (GGS).

Percent side lap = percent x size of frame x ground area = GGS

<u>Example</u>

30 percent side lap = 70 percent x 0.75 ft x 4000 ft = 2100 ft

Once the GGF and the GGS have been calculated, the number of photographs can be determined as follows:

<u>Forward Lap</u>

$$\text{No. of photos/flight line} = \frac{\text{Flight Line Length in ft}}{\text{GGF}} + 4 \text{ additional frames}$$

<u>Side Lap</u>

$$\text{No. of flight lines} = \frac{\text{Width of Mission Area in ft}}{\text{GGS}}$$

PHOTOGRAPHIC REQUIREMENTS

Vertical and oblique photography with CIR film has been done at various times with different formats and different cameras. Considerable research (ref. 3, 4, 5, 6, 8, and 14) has established that each format and camera system has its advantages and disadvantages. Results from work on this project have shown that the following photographic specifications and requirements will produce the best results for management of citriculture in Florida. For additional information concerning camera specifications and aerial photographic companies qualified by the Florida Department of Transportation, contact the Florida State Topographic Engineer (Table 1).

Camera Requirements

Previous work on citrus in Texas by Hart et al. (ref.8 and 9) indicated that the best format for citrus work was the 9 in. x 9 in. (23 cm x 23 cm) camera with a 12-in. (30-cm) focal length color corrected lens because of the critical requirements of photography in detecting tree stress. In com-

Fellsmere 4 SE Quadrangle
Florida
7.5 Minute Series (Topographic)

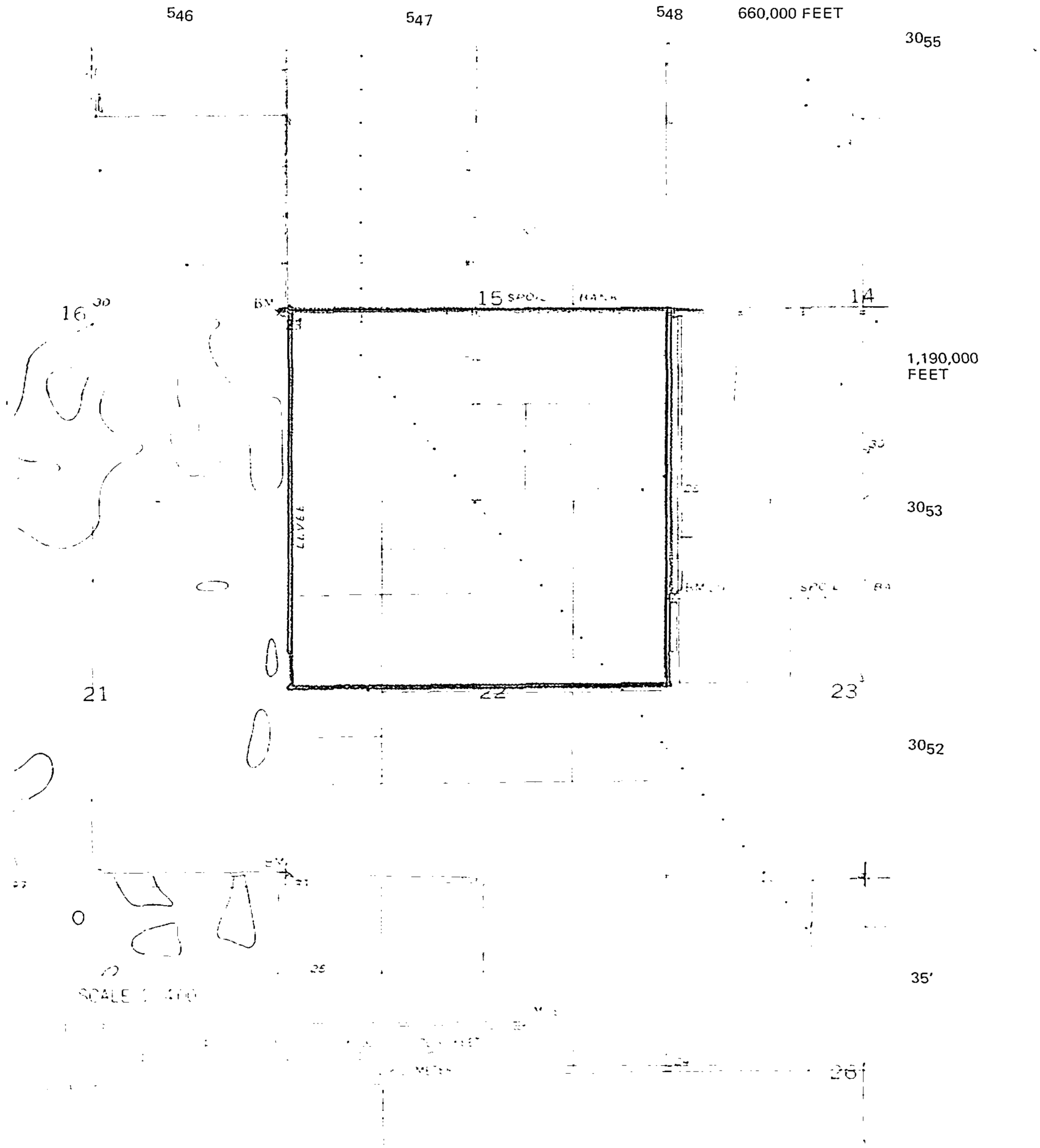
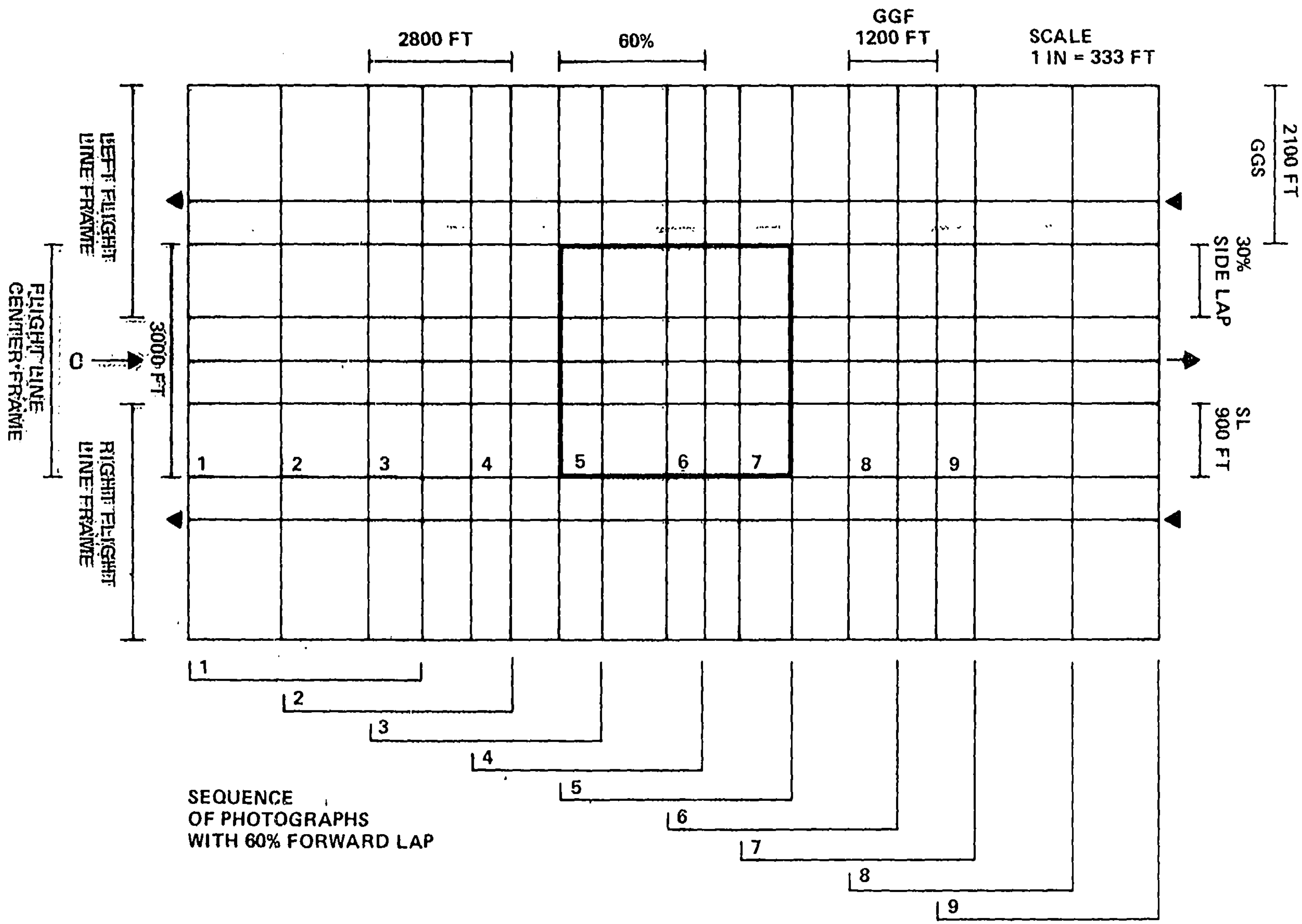


Figure 1. Photographic frame estimation template for 4000 ft. altitude. (Photographic frame estimation template for 4000 ft. (1219 m) altitude using a standard 7.5 minute U.S.G.S. Quadrangle Sheet. A means for rapidly calculating the number of photographic frames to cover 1 sq. mile (640 acres) using the forward and side overlap percentages in the text.)



parison with other commonly used aerial formats (70 mm or 4 in. x 5 in. (10 cm x 12.5 cm)) the 9 in. x 9 in. (23 cm x 23 cm) large format (when photography is taken at 4000 ft (1220 m)) has the additional advantages in that:

1. It is a standard for most aerial photographic companies

2. It covers large areas such as the vast groves in Florida

3. It can be easily photo-interpreted with simple and inexpensive equipment that small, medium, and large growers can purchase.

The 6-in (15-cm) focal length lens is preferred by aerial photographers for black and white (B&W) photography because it has a wider angle of view, thus covering greater acreage per photographic frame. Use of this lens allows aerial photographic planes to fly at half of the altitude required by the 12-in (30-cm) focal length lens to obtain the same scale, and is generally used to obtain topographic relief. A comparison between 6-in. (15-cm) and 12-in. (30-cm) focal length lenses in area coverage at different altitudes is presented in Figure 2.

The Zeiss, Wild, or equivalent camera systems are recommended. A yellow filter is needed to eliminate blue light (Wratten No. 12 or equivalent).

Film Requirements and Properties

The only ACIR film recommended is Kodak Aerochrome Infrared Film No. 2443. ACIR film was originally developed as a military reconnaissance tool to detect camouflaged installations. The ability of CIR film to detect differences in stress is due to sensitivity in a region of the infrared part of the electromagnetic spectrum and is well covered in the Appendix. Its sensitivity to stressed or damaged vegetation has made it highly useful in agricultural problem detection. The film is available in various widths, but this discussion is limited to the 9 in. x 9 in. (23 cm x 23 cm) width processed as a positive transparency.

Storage - Kodak Aerochrome Infrared Film No. 2443 requires more critical handling and processing conditions than other natural color or B&W films. The film must be stored in a frozen condition prior to use, processed immediately after use, or refrozen after exposure to avoid the severe effects of aging, humidity, and warm temperatures.

Single Batch Preference - Frequently, pronounced variations in color balance between different batches of film introduced during film manufacture can cause significant shifts in color of the finished product which introduces a problem of photo interpretation. It is therefore strongly recommended that all film for each mission be selected from the same batch, and to have enough film to meet the requirements of an entire year of photography.

Wedge Requirements - The use and comparison of density wedges before and after exposure of film is recommended as a precaution to ensure proper processing and handling of the film.

Light Limitations

ACIR photography of citrus groves is greatly affected by the amount of available light, the angle of the sun, and cloud cover. These factors greatly influence the photographic results and can make photo interpretation an easy or difficult operation.

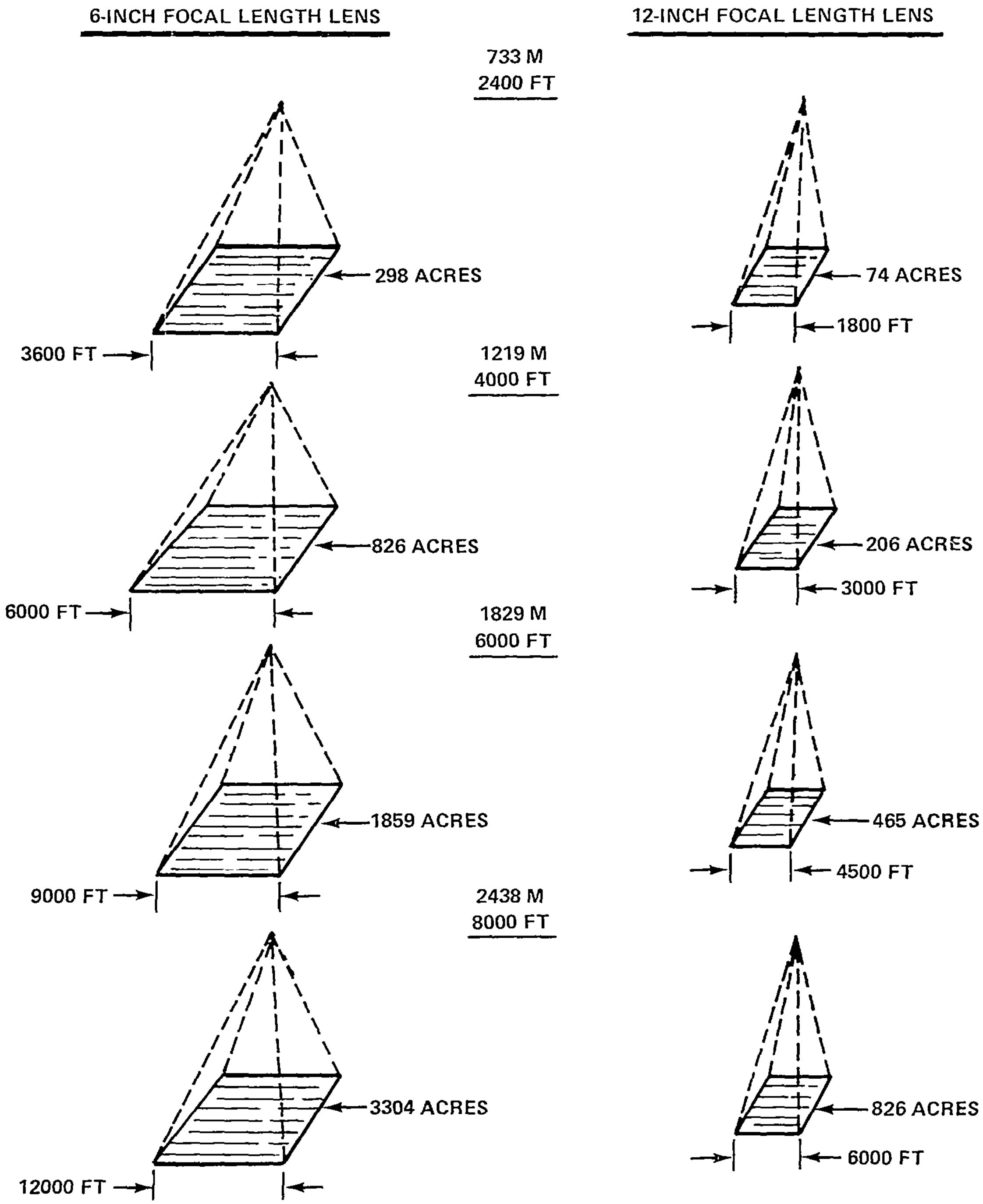


Figure 2. Comparison of area coverage with 6 inch and 12 inch lenses. (Comparison of area and side dimensions with 6-in. (15-cm) and 12-in. (30-cm) focal length lenses from 2,400 ft (733 m), 4,000 ft (1,219 m), and 8,000 ft (2,438 m) altitudes.)

Light Intensity and Sun Angle Effect - The primary factor governing successful ACIR photography is sun angle. Consequently, photography should never be attempted when the sun angle is less than 45 degrees from the Zenith. When the sun angle is less than 45 degrees, light intensity is insufficient for optimum results, and tree shadows already present will tend to be amplified. The best photography can be obtained when the sun is at its highest peak and trees produce little or no shadows that may cover adjacent or replacement trees. The variability of the sun angle during the day can be observed in Figure 3. The sun's peak angle is much greater throughout the summer than during the winter months so that it is possible to photograph during a greater number of hours of the day during the summer.

Exposure of Film - It is recommended that photographers unfamiliar with CIR film use the Eastman Kodak Company exposure index and carry out a test flight over the desired grove using various exposure settings, taking into consideration the various horticulture restrictions.

Sun Spot - An inherent problem with ACIR photography is a phenomenon called sun spot or hot spot. This term is defined as an elliptical area of bright reflectance (over exposure) coincident with the shadow of the aircraft and a darker area (under exposure) opposite. These phenomena are more pronounced with a 6-in. (15-cm) focal length lens than with the recommended 12-in. (30-cm) lens. The overexposed area centers on the plane's shadow and makes comparisons between trees within the sun spot area and the underexposed solar reflection area at the opposite side of the frame difficult to carry out (Figures 4 and 5).

A partial bright area (sun spot) can still be observed on a 12-in. (30-cm) focal length lens photograph with a darker area opposite the fall of object shadows; however, this is not objectionable, although some frames may be quite underexposed in darker areas. The major portion of the bright area in a 12-in (30-cm) focal length lens normally falls outside the photographic frame (Figure 5).

Another advantage of the 12-in. (30-cm) focal length lens is that it has little or no vignetting, which is a gradual underexposure in the outer edges and corners of the frame caused by the stopping of oblique light rays by the camera lens. This is a serious problem with 6-in. (15-cm) focal length lenses.

Scale of Photography

The scale of an image is expressed as the ratio of the image size on the photograph to the object's size on the ground. The numerator represents the size on the film, and the denominator indicates the object size on the ground. Example 1:333 means that 1 in. on the film represents 333 ft on the ground. Photographs can be obtained at the same scale with either the 6-in. or 12-in. focal lengths lenses, but they would need to be taken at altitudes of 2000 and 4000 ft, respectively (610 m and 1220 m). Conversely, the scale of 1 ft: 4000 ft (30 cm: 1220 m) (1 ft on the film is equivalent to 4000 ft on the ground) is the same as 1 in.: 333 ft.

Tests of the 9 in. x 9 in. (23 cm x 23 cm) format photography taken at three different altitudes indicated that the lowest altitude, 4000 ft (1220 m) with a 12-in. (30-cm) lens (Figure 6), was best because it could be analyzed with a simple viewing system. The intermediate altitude of 6000 ft (1830 m) (Figure 7) was also acceptable, although it was more difficult to see small details. The 8000 ft (2440 m) (Figure 8) high-altitude photography was as clear as the other two, but more ex-

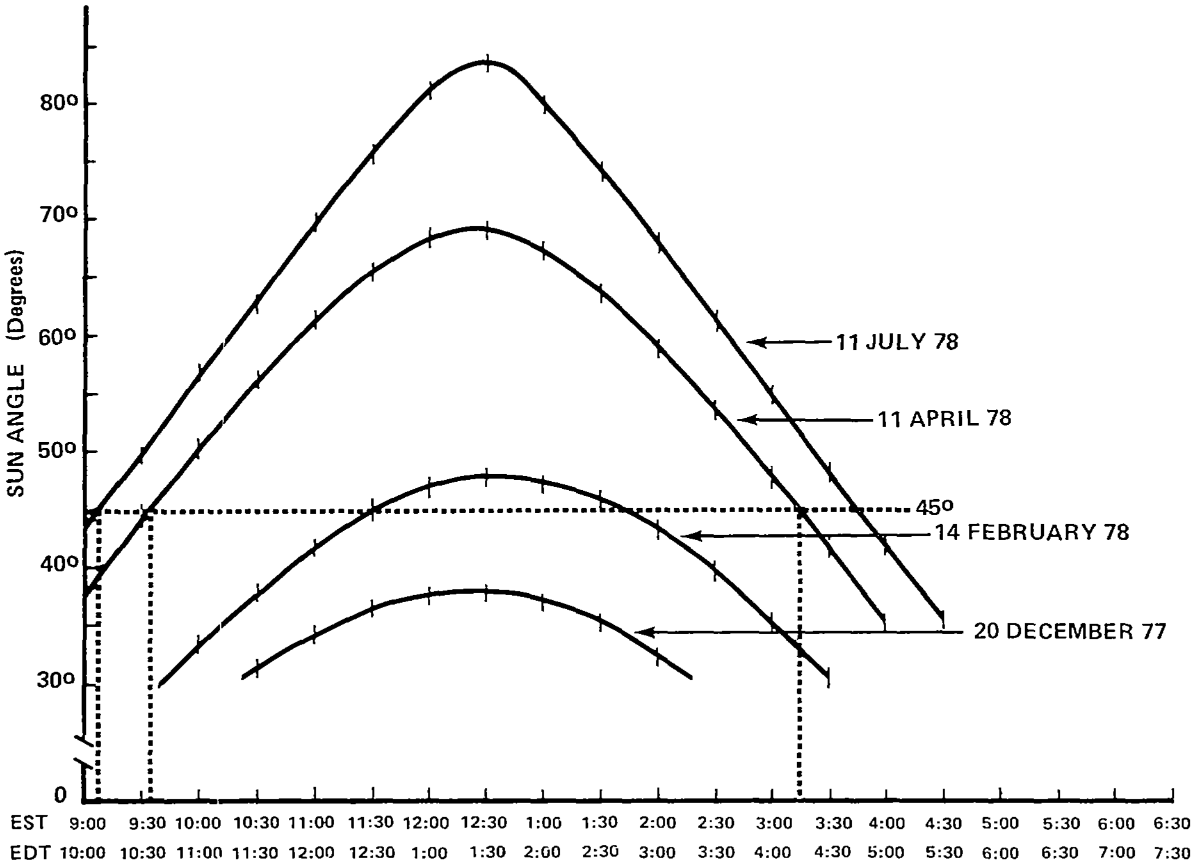


Figure 3. Sun angle variability. (Sun angle variability (in degrees) during the day for four photographic missions from December 22, 1977 to July 11, 1978 at the Lake and Orange County test sites. (Latitude 28 degrees, 40 min. North, longitude 81 degrees, 50 min. West.))

Figure 4. Sun spot photograph. (A spring (April 11, 1978) aerial CIR photograph of a Polk County grove photographed with a 6-in. (15-cm) focal length lens from 2,000 ft (610 m) altitude showing the sun spot where the airplane shadow is visible. Scale: 1 in. = 333 ft.)

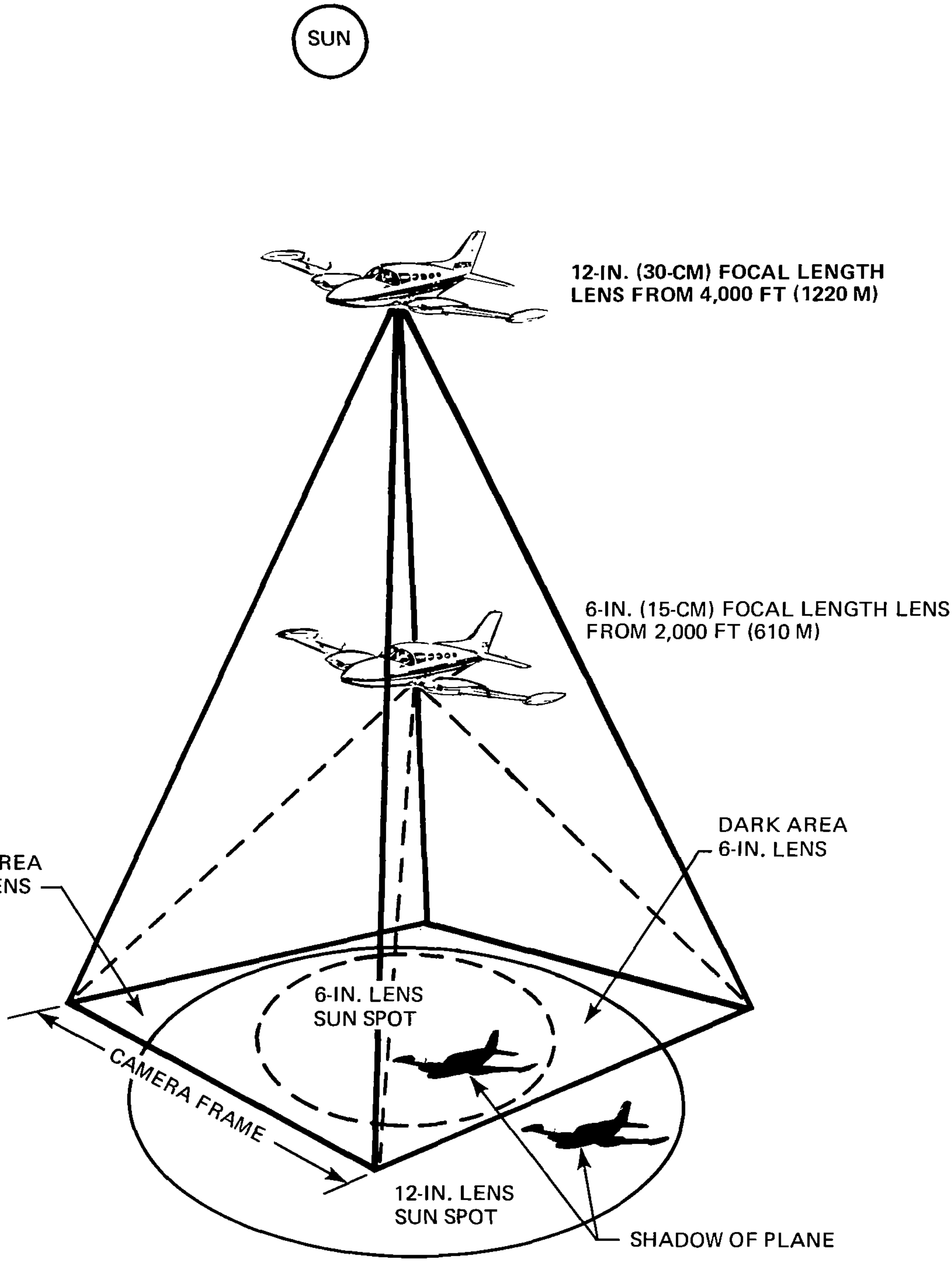


Figure 5. Diagram of the location of the sun spot and aircraft shadow. (Sun spot and photography aircraft shadow location comparison with 6-in. (15-cm) and 12-in. (30-cm) focal length lenses.)

pensive magnification devices such as a stereoscopic microscope are needed for critical analysis of the photography.

It is recommended that small and moderate sized grove owners adhere to the 4000 ft (1220 m) altitude because it yields the best combination of costs and simplicity of photo interpretation equipment. Growers who are willing to invest in more expensive photo interpretation equipment may be able to use smaller scale photography from higher altitudes.

The net gain in acres (hectares) per photograph must be taken into consideration when determining the scale of photography over a citrus grove. As can be seen in Table 2, the acreage gain per photograph varies considerably with the altitude and focal length of the camera lens used in the mission. It is misleading to estimate the number of photographic frames that will be required per flight line if the acreage gain per photograph is not used. Serious misunderstandings can occur between grower-user and aerial photographer if the process is not discussed (Tables 2 and 3).

Table 2. Acreage Gained Per Altitude Increase

Six-Inch Focal Length Lens		Per Photograph	
Altitude	Dimension	Acreage Photographed	Acreage Gain Per Photograph Due to Overlap
2400 ft	3600 ft	298	83
4000 ft	6000 ft	826	231
6000 ft	9000 ft	1859	520
8000 ft	12000 ft	3304	925
Twelve-Inch Focal Length Lens		**Per Photograph**	
Altitude	Dimension	Acreage Photographed	Acreage Gain Per Photograph Due to Overlap
2400 ft	1800 ft	74	21
4000 ft	3000 ft	206	58
6000 ft	4500 ft	465	130
8000 ft	6000 ft	826	231

Comparison of acreages gained per photographs taken with 6-in. (15-cm) and 12-in. (30-cm) focal length lenses, with 60 percent forward lap and 30 percent side lap.

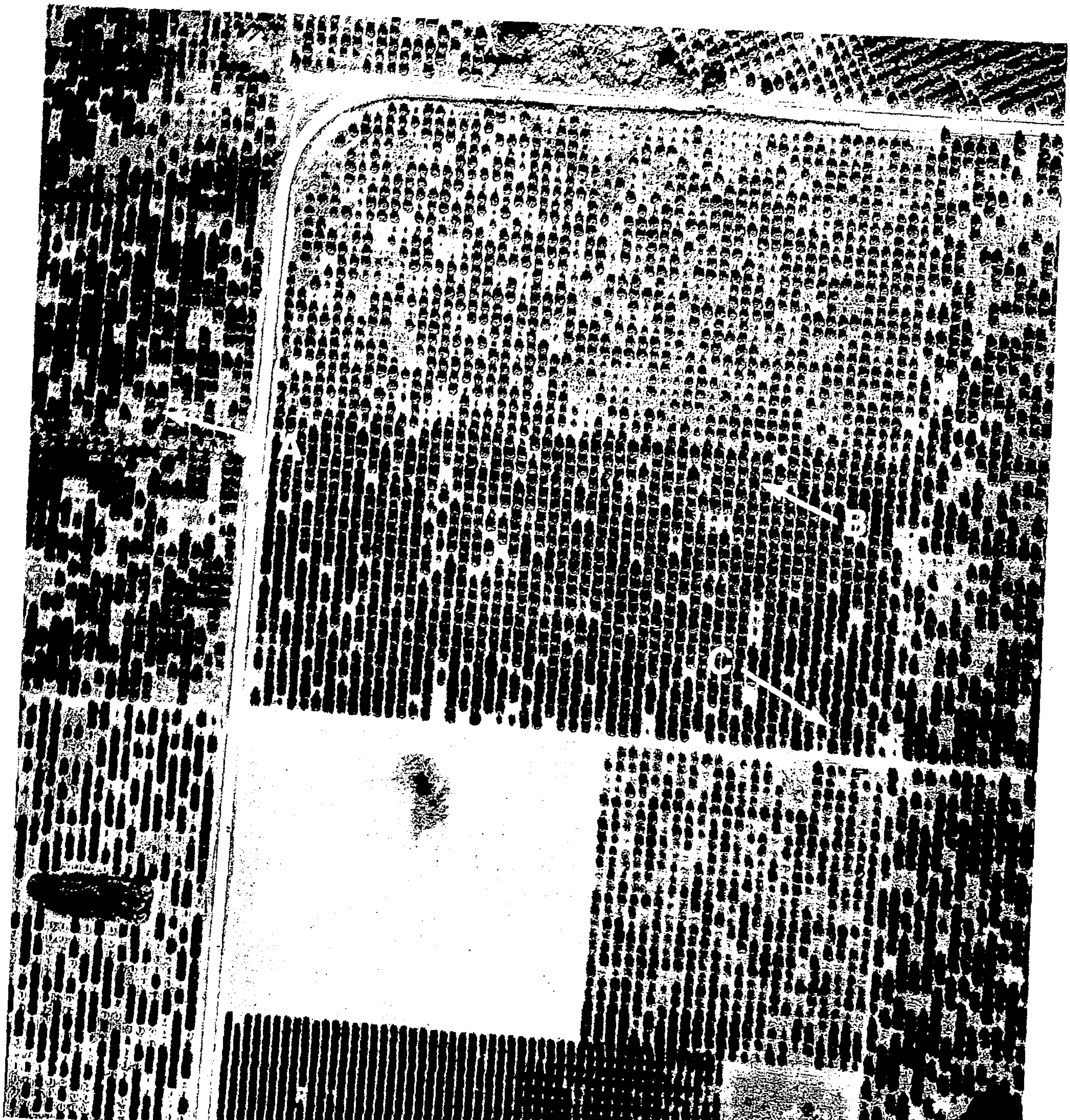


Figure 6. Aerial CIR photograph of a Lake County grove from 4,000 feet (1,219 m). (A winter (December 22, 1977) CIR photograph of a citrus grove in Lake County, Florida, taken from 4,000 ft (1,219 m) with a 12-in. (30-cm) focal length lens and a yellow filter (Zeiss C). Scale: 1 in. = 333 ft. A dead tree with vines on top can be seen at A, a No. 2 tree can be observed at B, and a No. 1 tree can be detected at C.)

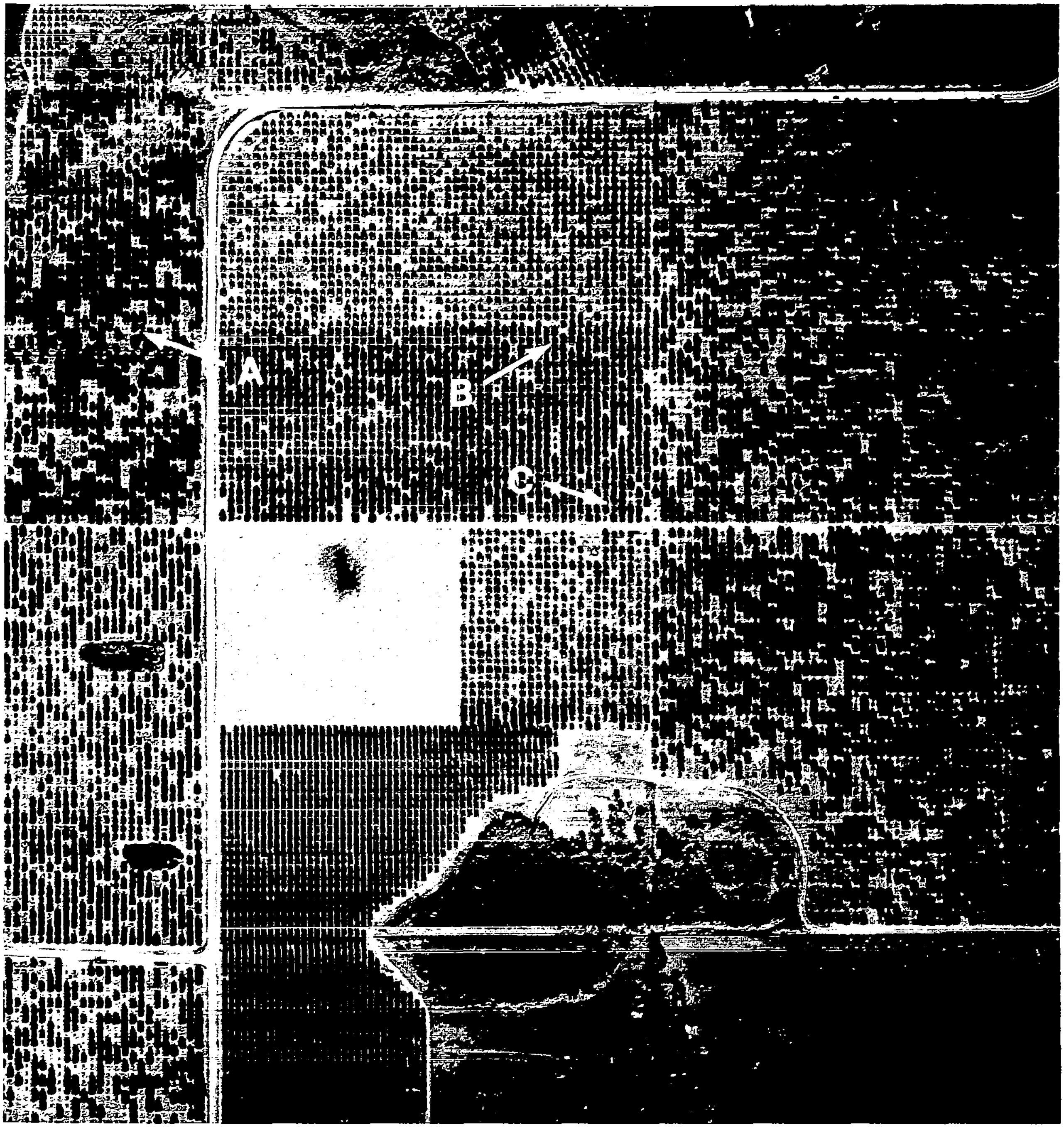


Figure 7. Aerial CIR photograph of a Lake County grove from 6,000 feet (1,829 m). (A winter (December 22, 1977) aerial CIR photograph of a citrus grove in Lake County, Florida, taken from 6,000 ft (1,829 m) with a 12-in. (30-cm) focal length lens and a yellow filter (Zeiss C). Trees in various conditions of health can be seen at A, B, and C. Scale: 1 in.= 500 ft. A dead tree with vines on top can be seen at A, a No. 2 tree can be observed at B, and a No. 1 tree can be detected at C.)

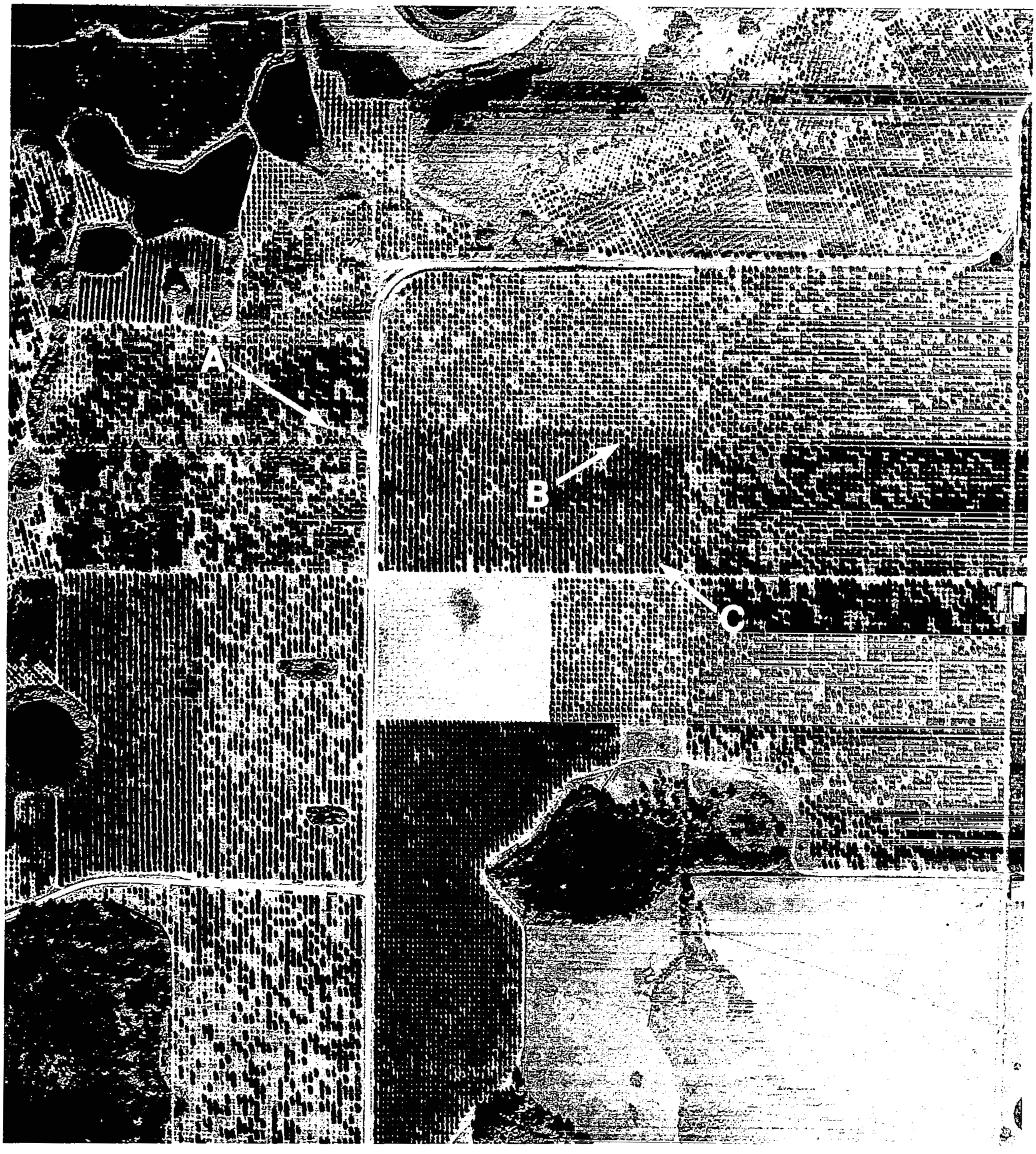


Figure 8. Aerial CIR print of a Lake County grove from 8,000 feet (2,438 m). (A winter (December 22, 1977) aerial CIR photograph of a citrus grove in Lake County, Florida, taken from 8,000 ft (2,438 m) altitude with a 12-in. (30-cm) focal length lens and a yellow filter (Zeiss C). Scale: 1 in. = 660 ft. A dead tree with vines on top can be seen at A, a No. 2 tree can be observed at B, and a No. 1 tree can be detected at C.)

Table 3. Total Acreages (Hectares)
Per Altitude Change

Photographic Scales: U. S. Standard vs Metric Conversion

System	Altitude	Scale	Area
U. S. Standard	2400 ft	1 in. = 200 ft	74.0 Acres
Metric	732 m	1 cm = 24 m	30.0 Hectares
U. S. Standard	3000 ft	1 in. = 250 ft	116.0 Acres
Metric	915 m	1 cm = 30 m	47.0 Hectares
U. S. Standard	4000 ft	1 in. = 333 ft	206.0 Acres
Metric	1220 m	1 cm = 40 m	83.4 Hectares
U. S. Standard	6000 ft	1 in. = 500 ft	465.0 Acres
Metric	1830 m	1 cm = 60 m	188.25 Hectares
U. S. Standard	8000 ft	1 in. = 660 ft	826.0 Acres
Metric	2440 m	1 cm = 79.3 m	334.0 Hectares
U. S. Standard	12000 ft	1 in. = 1000 ft	1859.0 Acres
Metric	3660 m	1 cm = 120 m	752.6 Hectares

Photographic scales with both the U.S. standard and Metric equivalents for different altitudes showing the area per frame covered by photography from varying altitudes with a 12-in. (30-cm) focal length lens.

HORTICULTURAL RESTRICTIONS

A number of factors affect aerial photography and restrict the use of ACIR film for citriculture management. These factors, which were verified in the ACIR experiment and grower demonstration, are discussed below.

Best Season for Photography

The greatest differences between healthy and stressed trees were observed during the spring flush season after most of the flowers had fallen and the young leaves were yellowish green and pliable, that is, they had not hardened and changed to a darker green. Differences between healthy and stressed trees can be observed at other times, but differences in degrees of stress can be observed more readily on transparencies taken during the spring flush season.

Planting Distances

The spacing of trees has a considerable effect on ACIR photography because it influences photographic parameters. The standard planting in the Florida ridge district (equidistant rows and trees), or partial row (closer spacing within trees in a row) does not greatly affect the photographic exposure. The south Florida type of planting where trees within a row are closely spaced with four to 13 rows on a raised bed, does affect exposure considerations when the trees reach production stage.

Canopy Density

The planting distance of trees, their age, and other horticultural and environmental factors determines the size and density of tree canopy, thus greatly affecting the amount of light reflected by bare soil between trees (Figure 9).

Varietal Differences

Citrus varieties produce young foliage (flushes) at different times of the year depending on climatic conditions, geographic locations, and soil types. Trees may produce two or more principal flushes during the year, with the largest crop of fruit produced during the spring flush. The spring flush was chosen for the experiment, and is also recommended as the optimum time for grove photography.

Background Effects

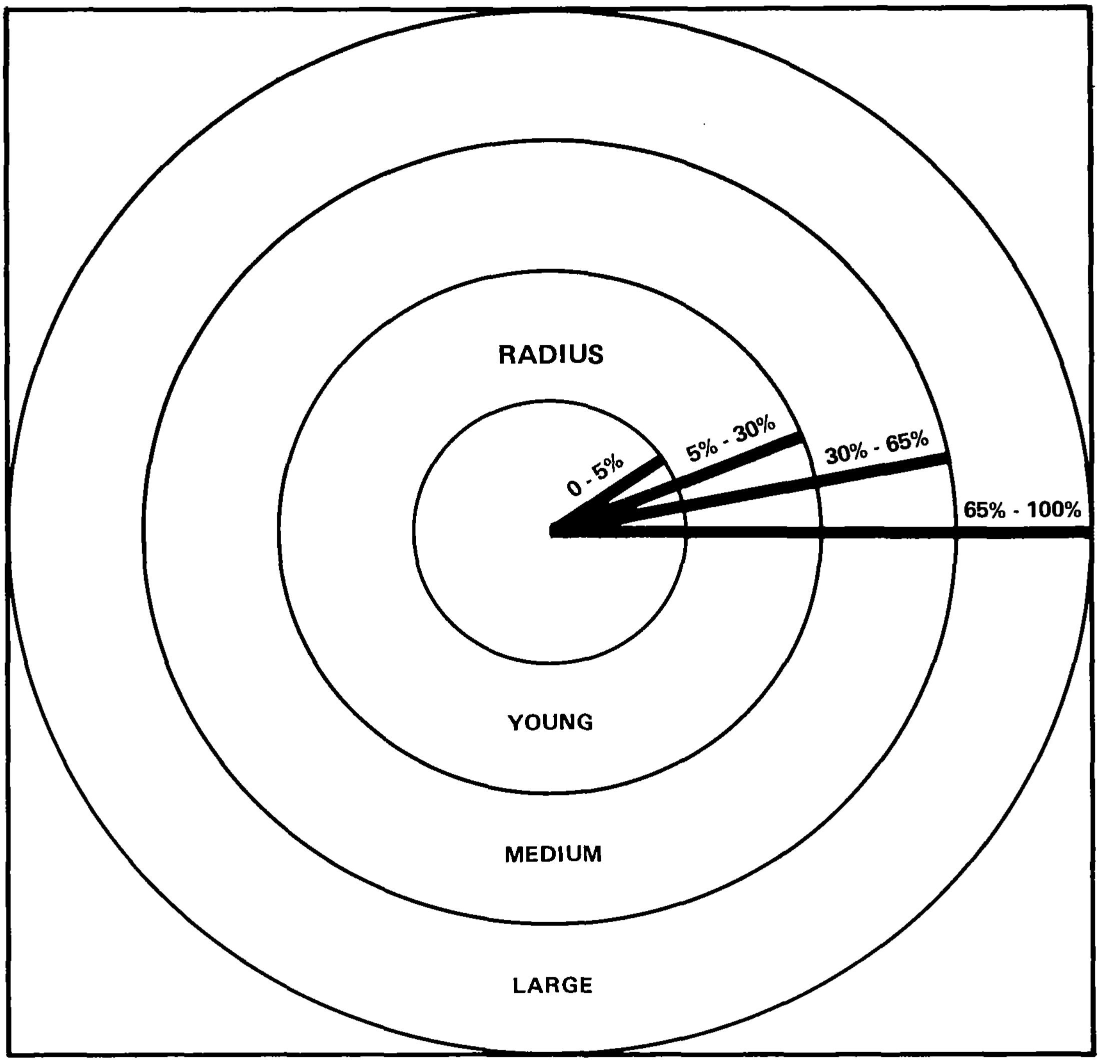
A number of factors influence background reflectance in ACIR photographs of citrus groves. These factors may occur simultaneously in some cases. The most important background effects are as follows:

Changes in Soil Types - Soil type varies among groves. This may be more pronounced in some groves in south Florida, but soil type variability is also considerable in the central Florida ridge district (Figure 10). Soil types vary greatly in color and consequently change the range of exposure settings.

Undesirable Vegetation - Vegetation in a citrus grove that interferes with tree growth is undesirable. This can be classified into vines that cover the tree tops or grow within the canopy, and grasses and weeds distributed over the ground. It is most important to verify the identity of these vines, as in some cases they may cover and change the appearance of dying or dead trees. Grasses interfere with photo interpretation of young, replacement, and nursery trees. If grasses and ground weeds are not mowed or herbicide sprayed before photographing, it may be necessary to make an exposure correction to avoid underexposing the transparency (Figure 11).

Moisture - Moisture is an important variable affecting the reflectance of background soil and vegetation. Reflectance of wet soil is considerably less than that of dry soil. Heavy rains prior to the photography may necessitate an exposure correction to avoid underexposing the transparency. Irrigation problems as well as other differences in soil moisture is easily detected with ACIR photography; however, it is difficult to quantify moisture differences because there is no instrument that can accurately and rapidly measure soil moisture on a scale large enough for use in ground verification of ACIR photography (Figures 12, 13, and 14).

TREE CANOPY



POTENTIAL GROWING AREA

5% OR LESS OF RADIUS = RESETS

5% TO 30% OF RADIUS = YOUNG

30% TO 65% OF RADIUS = MEDIUM

65% AND OVER OF RADIUS = LARGE

Figure 9. Schematic diagram for measuring or estimating tree canopy size. (The square represents the potential outer boundary of the tree space as determined by planting distance.)

Figure 10. Changes in soil types. (Black and white copy of a 9 in. x 9 in. (23 cm x 23 cm) ACIR transparency showing changes of soil type which vary from dark sandy soil to white sandy soil.)

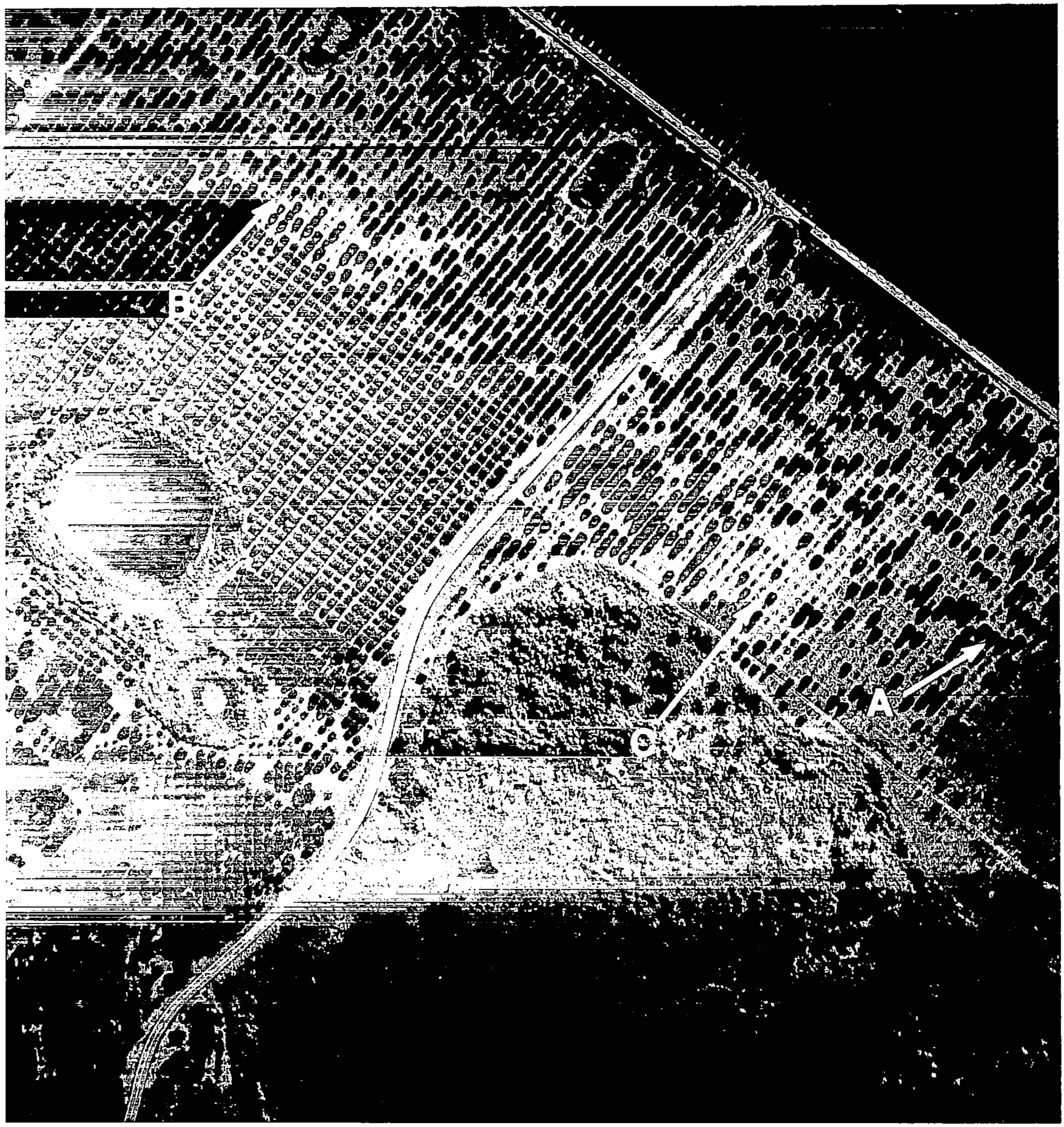


Figure 11. Summer photograph of a Lake County grove showing grass and shadows. (A summer (July 11, 1978) aerial CIR photograph of a grove in Lake County, Florida, taken at 9:30 a.m. Eastern Daylight Time and showing: A. Excessive shadows block the observer's view of replacement trees. B. Luxuriant grass growth is visible throughout the grove. C. Ringed replacement and young trees. Scale: 1 in. = 333 ft.)

PHOTOGRAPHIC PRODUCT REQUIREMENTS

The first aerial photographic mission over a citrus grove will be the most difficult and possibly the costliest, due to the preparation that must go into the initial mapping and registration of each transparency over a specific flight line.

The initial product of a mission flown using ACIR film is a positive transparency because it is easier to interpret and less costly than color prints.

Enlargements

Enlargements of certain areas of groves selected during photo interpretation expedite ground verification. Enlargements with mylar overlays, properly marked with the grid cell system, will accelerate the ground verification operation substantially, (See page 53 for use of enlargements). It will also provide a permanent record that can be compared with the CIR transparencies for additional confirmations (Figure 15).

Optional Contact Prints

Regular B&W 9 in. x 9 in. (23 cm x 23 cm) contact prints of the CIR transparencies may be extremely helpful to produce the first group of flight lines and eventually a mosaic of the grove. These contact prints, while expensive, are far superior to the 2- or 4-year old Property Appraiser blue-line maps, since they contain current information on grove condition and will aid in the selection of the best frames to use for enlargement for ground verification/grove maps.

High Altitude Photography

An alternative to the expensive contact prints from ACIR transparencies is the use of a separate high-altitude photographic mission with B&W film at 10,000 ft (3048 m). This would cover most of the area with a few frames that can be enlarged to a scale of 1 ft = 660 ft (30 cm = 201 m) or to a larger scale of 1 in. = 100 ft (2.5 cm = 30 m) for grove verification tests.

WRITING OF CONTRACTS

Agreements between citrus growers and aerial photographers for aerial photography missions using CIR film may be accomplished with a specific contract or an informal letter of authorization. Most aerial photographers prefer to use letters of authorization because they are usually tailored to the needs of a particular client. *It is mandatory that the photographer understands that he must use an infrared color-corrected 12-in. (30-cm) focal length lens.* The contractual agreement or authorization should detail the required photographic specifications of a specific grove, the desired mapping area, and the agreed fee.

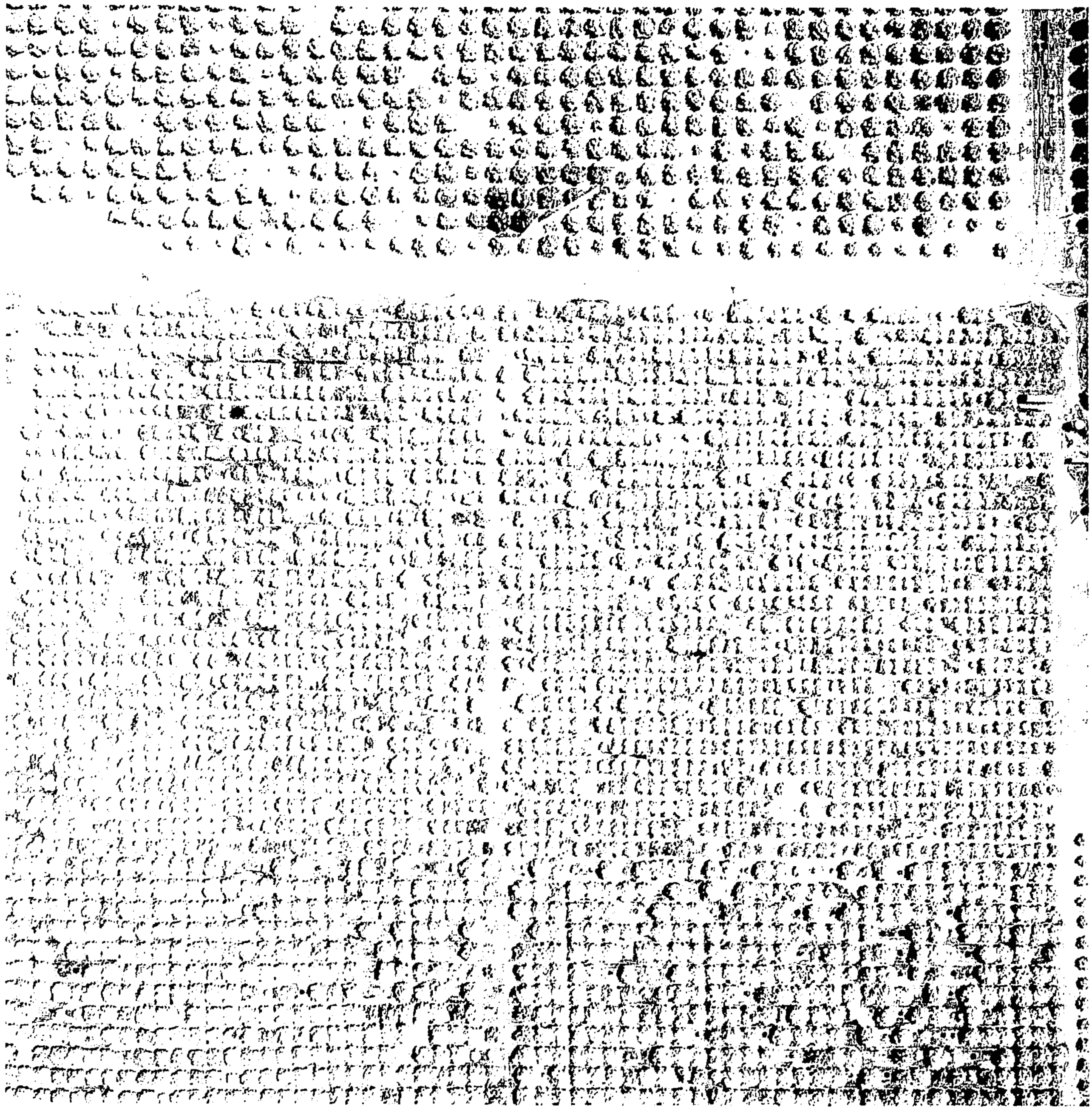


Figure 12. Sprinkler system in a grove in Polk County. (A spring (April 6, 1978) aerial CIR photograph in Polk County, Florida, showing the: A. Wet rings produced by sprinklers. B. The location of faulty sprinklers. C. The seepage of water across the road to an adjacent grove. Scale: 1 in. = 200 ft.)

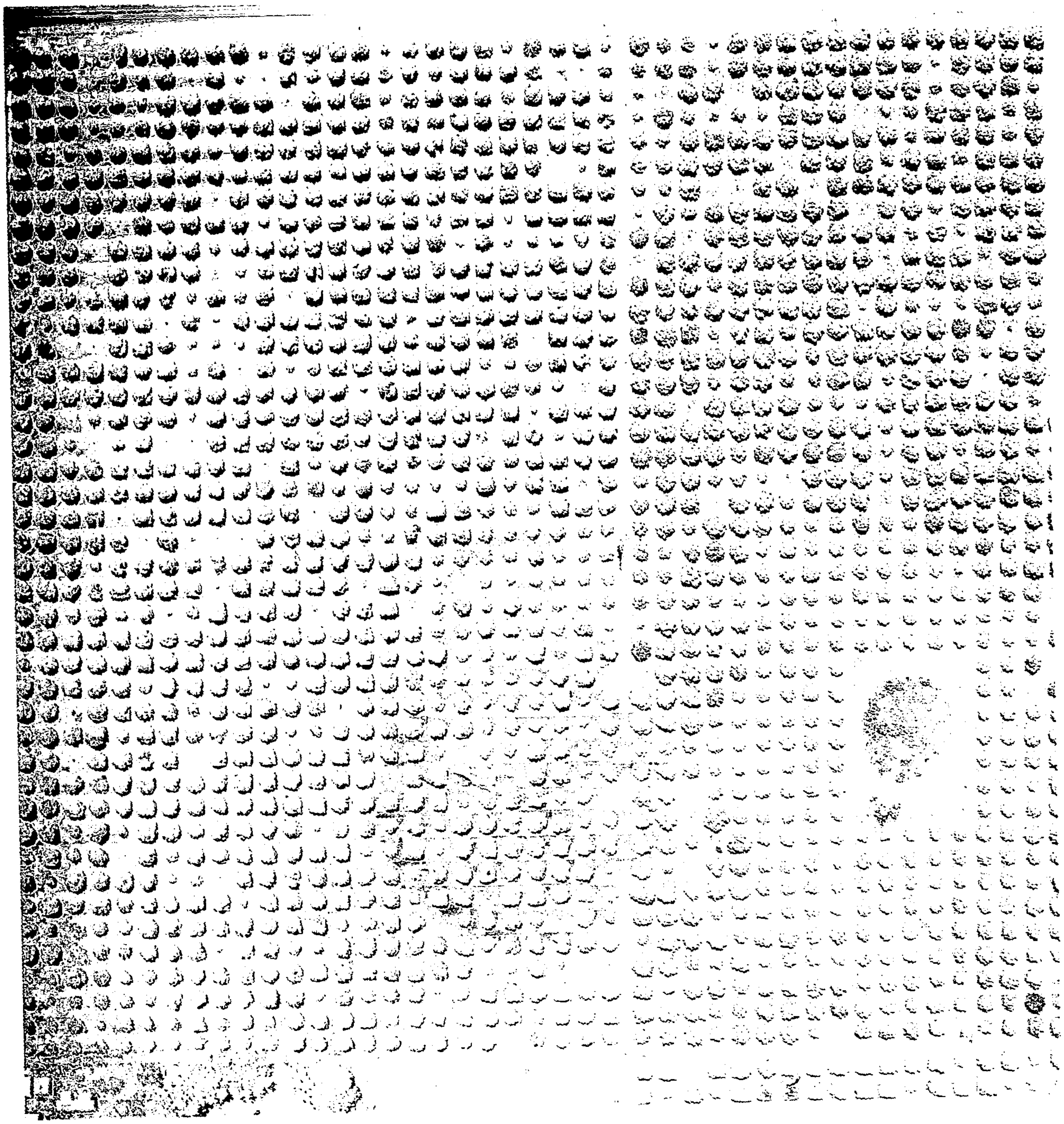


Figure 13. Effect of rainbird down the row. (A spring (April 6, 1978) aerial CIR photograph in Polk County, Florida, showing the effect of water from a rainbird as it moves down the row of trees. Scale: 1 in. = 200 ft.)

Figure 14. Pipe irrigation in a grove in Polk County. (A spring (April 11, 1978) aerial CIR photograph in Polk County, Florida, showing moisture distribution throughout a two row area from an irrigation water pipe. Scale: 1 in. = 333 ft.)

PHOTO INTERPRETATION

1	●	2	1	1	1	–	1
●	1	●	Λ	1	●	1	●
2	2	1	●	●	●	1	1
Λ	–	1	3	●	Λ	1	Λ
Λ	1	1	●	1	3	3	R
●	2	●	–	R	●	–	R
●	1	●	1	●	●	Λ	Λ
●	●	–	●	●	●	●	Λ

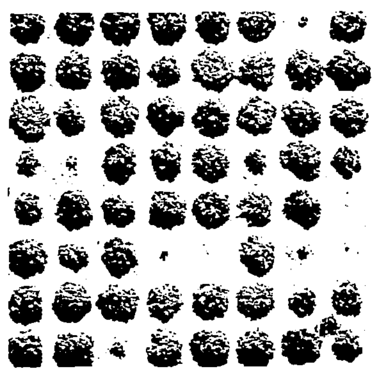


Figure 15. Comparison of photo interpretation and ground verification--single cell. (Comparison of photo interpretation and ground verification with a mylar overlay over a cell in a grove in Lake Alfred, Florida. The enlargement was made at the scale of 1 in. = 120 ft (2.5 cm = 37 m). The characters used above indicate tree condition and are described on page 60.)

GROUND VERIFICATION

1	●	2	1	1	1	–	1
●	1	●	∧	1	●	1	●
2	2	1	●	●	●	1	1
∧	–	1	3	●	∧	1	∧
∧	1	1	●	1	3	3	R
●	2	●	–	R	●	–	R
●	1	●	1	●	●	∧	∧
●	●	–	●	●	●	●	∧

MISSION IMPLEMENTATION

After all the necessary and desirable preparations for flight are completed, the growers and photographers should coordinate their schedules to implement the photographic mission.

AERIAL PHOTOGRAPHIC MISSION

Many mission variables can be modified as necessary to complete the flight; however, the weather variable is a factor, not controlled, which determines the success or failure of the mission.

Weather Variables

Photographic missions must be flown in near-perfect weather conditions. Cloud cover, wind direction and velocity, and haze are conditions, either singly or in combination, which can delay or cancel the mission. It is always best to select cloud-free days, but if scattered clouds are present, it may be necessary to stay aloft and photograph when the clouds have moved out of the targeted area. It is suggested that contracts specify flying only when local forecasts predict 10 percent or less cloud shadow impingement on the grove area. Excessive turbulence can also interfere with photographic efforts and can cause cancellation of the mission.

Mission Accomplished Same Day

Light and weather conditions are difficult to duplicate, so it is always desirable to complete a photographic mission the same day, with the same sun angle restrictions. Aerial photographers should have all equipment in good order. The pilot must insure that sufficient flying time is available to complete the mission prior to a planned maintenance/inspection. Delays are not only costly, but the flush on the trees may last 10 to 15 days at the most.

Flight Logs

Records of photographic missions are an important part of the mission and must be furnished by the aerial photographer to the citrus grower. In addition, if a discrepancy occurs, it is important to the photographer to know what went wrong, and possibly prevent it in the future. Flight logs were extremely useful in both the ACIR photographic experiment as well as in the grower demonstration to clarify the results obtained in the photography. Flying conditions, flight line number and direction, lens openings, shutter speed, time of photography, and counter numbers should be logged.

Film Identification (Frame and Counter Numbers)

It is standard practice for aerial photographers to number each frame with a job number, date of flight, flight line number, and frame number. Frame and counter numbers are quite helpful in identifying both the direction of the flight line and the specific frame. These records are the key to the registration of the flight line over the flight lines drawn on the Tax Assessor's blue-line maps.

While experienced photo interpreters and aerial photographers can assemble a flight line without counter and frame numbers, recording them saves time and lessens confusion to the less experienced.

ACCEPTANCE OF AERIAL PHOTOGRAPHY

A conference should be held between the aerial photographer and citrus grower to review the aerial photography obtained. It is a good business practice and will eliminate potential problems if both individuals (or their representatives) verify the results obtained prior to acceptance and payment. *The desired items to check are:*

1. That cloud conditions are acceptable

2. That the desired acreage was photographed at the proper altitude, generally recommended to be 4000 ft (1220 m)

3. That the photographer has properly labeled the film frames

4. That all photography is within the acceptable exposure ranges

5. That the proper overlaps (60 percent forward and 30 percent side lap) were obtained

6. That the acceptable color balance was obtained in processing.

GROWER FILM LABELING AND FRAME REGISTRATION

The product of the photographic mission is a roll of film processed as positive transparencies of various lengths depending on the size of the grove photographed. The need for pre-flight data preparation and for a grove map becomes evident when organizing the transparencies and identifying the various blocks, beds, sectors, quadrants, and cells of the individual grove. Film identification errors can be minimized if the grove map with flight lines is used as a reference in the first viewing of the film for labeling, registration, and cutting. Lint-free cotton gloves must be worn at all times when handling the film.

Location of the flight lines on the Tax Assessor's blue-line map follows the labeling of the uncut film. After locating the starting area of the flight on a grove map and marking the flight line number on the blue-line map, the film should be rolled to the last frame of that particular flight line and the last frame registered on the grove map. Each flight line should then be marked in a similar fashion with the appropriate frame numbers and possibly with different color felt-tip pens to improve identification.

Since flight lines are not always flown from the same direction, care must be taken to correctly register each flight line. Topographic features, irrigation structures, sheds, or power lines should be used for proper orientation.

Once all the flight lines have been drawn on the map with different color felt-tip pens, it is necessary to locate each frame on each flight line for rapid identification and future reference. Area and bed numbers can be marked with a permanent transparent 3M (No. 15-1120-3) felt-tip pen on a section of the film frame that will not interfere with photo interpretation. Alcohol (a 30-percent ethanol solution) will remove any marking errors. It is best to start at the first flight line and number all the frames successively to avoid excessive rolling of the spool of film.

FILM CUTTING

The most expedient and convenient method to store cut 9 in. x 9 in. (23 cm x 23 cm) transparencies is to place them in 9-1/2 in. x 12 in. (24 cm x 30 cm) transparent plastic page protectors. Without such page protectors, normal handling will soon damage or deface film beyond practical use. Film cutting is normally done by two individuals. One cuts, while the other annotates the pertinent information from the map and film onto the transparent plastic page protectors.

Page Protector Labeling

The identification required on the film protector includes:

1. Job number
2. Date of flight
3. Roll number
4. Flight line
5. Frame number
6. Camera counter number (if available)
7. Grove
8. Block or area
9. Bed number (if available).

Due to forward and side lap, each area of the grove will appear in more than one photograph. It is best to record on a page protector all the areas appearing in each frame, underlining the area which has the best exposure and is easiest to photo interpret. If beds are included in the transparency, also record their identification number.

Frame Registration After Cutting

In large groves, a complete or entire block may not be photographed in one frame, so it will be necessary to locate the other frames covering the specific block and match them for ease in identification. It is best to assemble all frames of each block together in sequence. As an additional reference to the entire mission, a large sheet of graph paper should be used to mark each flight line, recording the identification found on each frame, and the sequence of beds recorded on grove maps. This flight line/grove map is used as a general reference for rapidly locating both areas and frames in the grove.

PHOTO INTERPRETATION

Photo interpretation of ACIR transparencies requires that the user have the proper equipment and experienced personnel to extract the information from the transparency. They must understand the seasonal effects on vegetation and be capable of confirming results with ground verification.

CHOICE OF EQUIPMENT

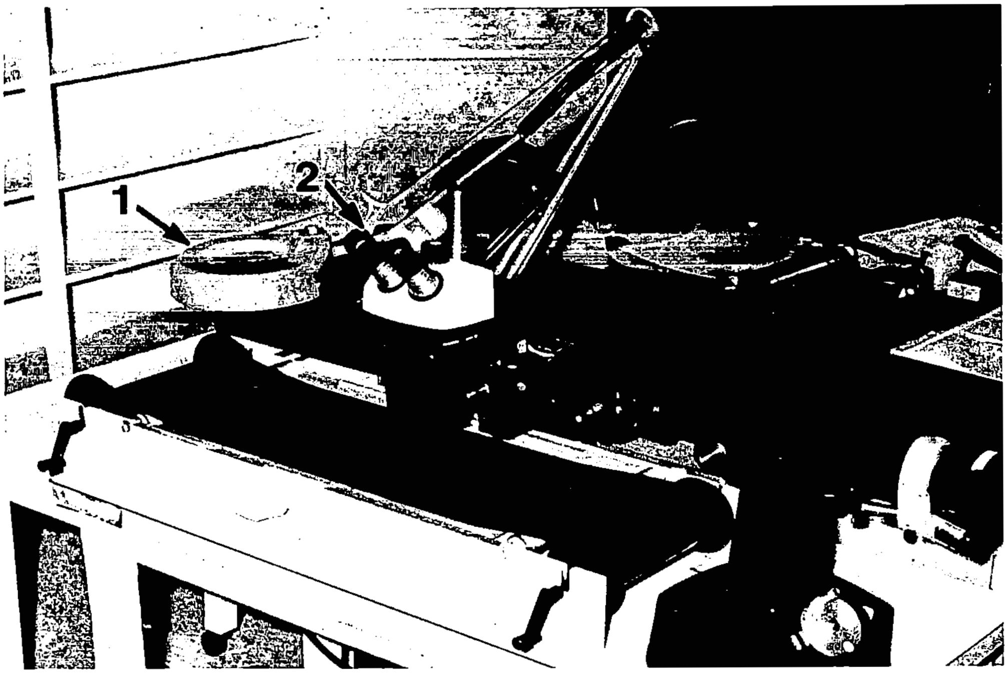
Professional photographic interpretation equipment is quite expensive and somewhat complex to operate. Early in the planning of ACIR photographic missions, it was determined that the best way to promote grower acceptance of CIR photography was to select the simplest and least expensive photographic equipment that could be used effectively by all growers. Another criterion used when choosing equipment was the ability to upgrade it, so that growers could improve on their original selection. The system can be improved by adding components such as stereoscopic dissecting microscopes, high-powered enlarging lenses, and a copying camera to prepare 35 mm copies of specific areas from the large 9 in. x 9 in. (23 cm x 23 cm) photographic frames.

Light Table

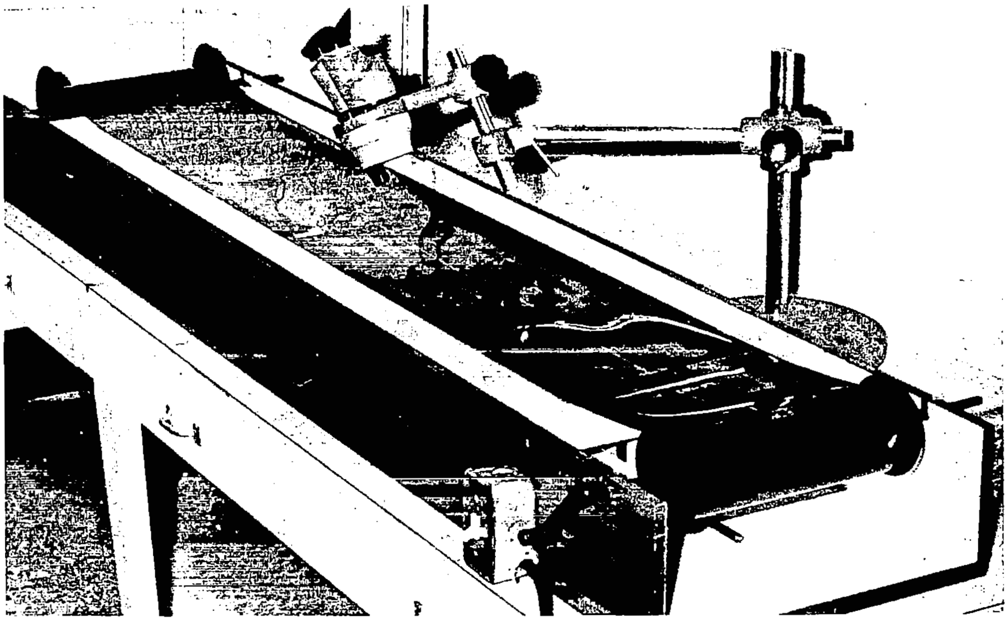
Small growers who do not have many frames to interpret would only require a small 2 ft (60 cm) light table. Medium acreage growers with a larger number of frames to photo interpret may require both a small and a large 4 ft (120 cm) light table. Large growers with extensive acreages will probably carry out a continuous photo interpretation operation throughout the year. Growers may desire to expedite progress by acquiring an additional set of small and large photo interpretation tables (Figure 16). Light tables can be constructed cheaply and easily with simple carpentry tools and four 40-Watt daylight fluorescent light fixture components. They may also be purchased ready made from photogrammetric, medical, or biological supply houses (X-ray light boxes). It is essential that all tables, whether constructed or purchased, be able to handle roll film without scratching or damaging it.

Magnifying Lenses

Photo interpretation of ACIR transparencies, taken at the recommended altitude of 4000 ft (1220 m), can be easily done with simple inexpensive magnifying lenses. The most versatile of the magnifying lenses (Figure 17) is the fixed-stand magnifier (with or without lamps). It is the least tiring and the most effective in photo interpretation since large areas of the transparency can be observed simultaneously with the three diopter magnification (3X) which is generally available. The most useful complementary magnifiers are the reading magnifier glass (3X) and a measuring closeup lens (comparator with 12X). The additional lenses are needed to verify specific problems in identification observed with the 3X fixed-stand lens. Individual photo interpreters may prefer one type over another or may choose better lenses than the ones described above.



A



B

Figure 16. Large and small photo interpretation tables. (Two examples of photo interpretation tables used at AREC Lake Alfred. A. Small light table 2 ft. long with (1) a 3X diopter lens/lamp combination and (2) an expensive stereoscopic dissecting microscope on an extension arm. B. A large light table 4 ft. long with a simple and less expensive stereoscopic microscope on an extension arm.)

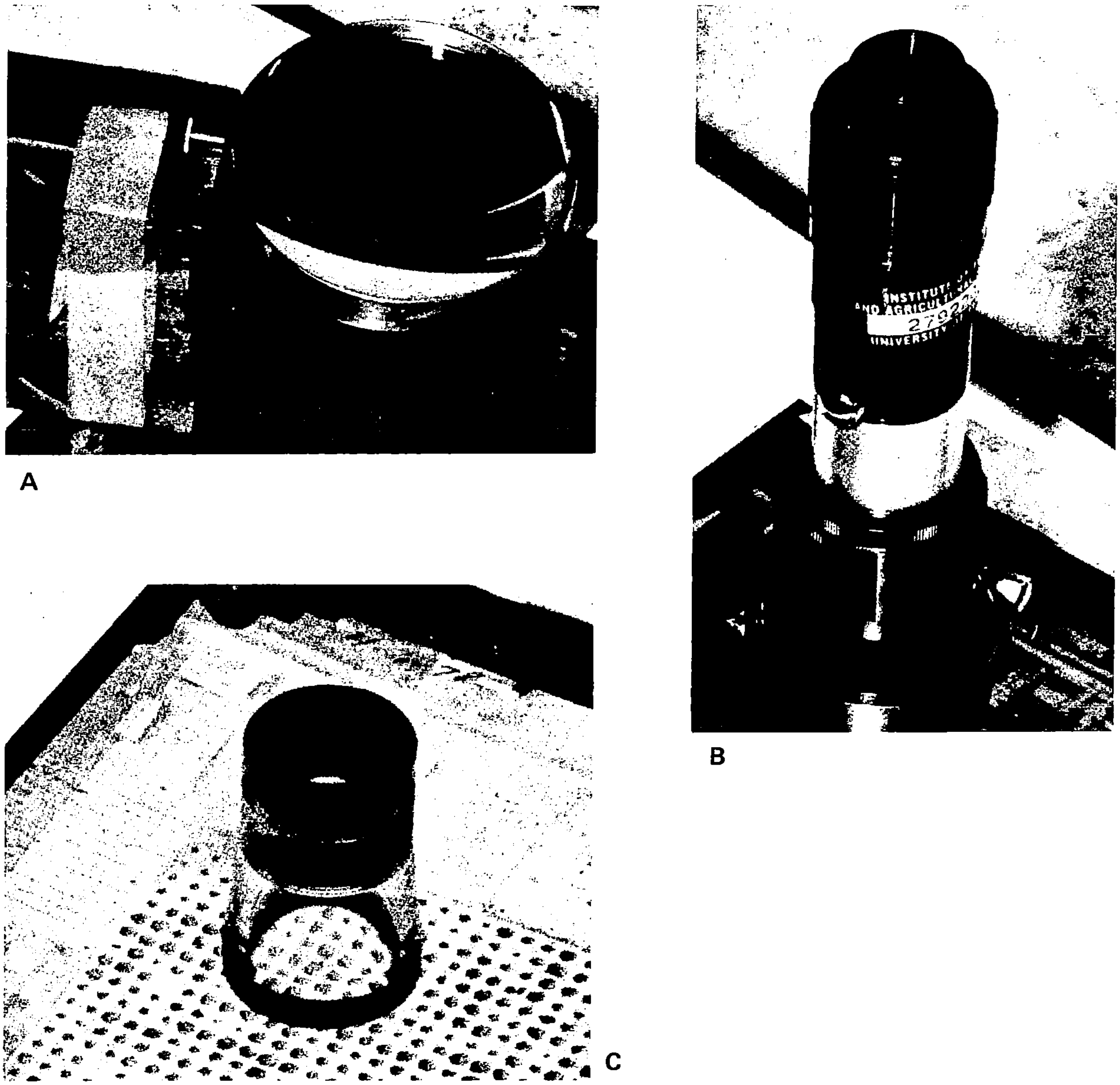


Figure 17. Hand lenses. (Three types of magnifying lenses that can be used for photo interpretation of aerial CIR transparencies alone or in combination with the lamp-mounted magnifying lens. A. Standard hand lens mounted on wooden blocks. B. Close-up magnifying lens with zoom capabilities. C. Standard close-up magnifying lens.)

Dissecting Stereoscopic Microscopes

The use of dissecting microscopes is considered to be attractive only to large growers requiring photo interpretation of a large number of transparencies who are willing to invest more than nominal amounts in procuring equipment. It is a more accurate instrument providing information much more rapidly and easily than the lower magnification of the fixed-stand lens. There are a number of microscopes available from various manufacturers and they can be obtained from scientific supply houses.

35 MM Copying Cameras

Thirty-five millimeter copying cameras may prove useful to large growers who wish to reproduce 35 mm color transparencies or B&W copies of specific areas of interest. These duplicates can be filed or stored in a different department of a citrus company and used for management conferences without repetitive handling of the original large transparency.

Microfiche Viewers

Standard microfiche viewers are a very useful tool permitting rapid scanning of original 9 in. x 9 in. (23 cm x 23 cm) transparencies to select specific areas or sites for further observation on light tables. They are also most useful in making comparisons between 35 mm copies for differences which include:

1. Dates of photography
2. Sites of a grove
3. Photographs of an area at different scales
4. Tree conditions of a grove.

Microfiche viewers can also be used in lieu of projectors in small presentations or conferences.

Thin Glass Plates

Thin, good quality, glass plates with taped edges (12 in. x 12 in. (30 cm x 30 cm)) are necessary to prevent damage to a specific transparency when the transparency is to be traced. Glass plates are also useful in holding the film flat to the surface of the light table.

Expendable Items

There are few expendable items; however, the most important ones are:

1. Mylar (transparent plastic) film, useful in the preparation of overlays

2. 3M permanent felt-tip marking pens (No. 15-1120-3 or equivalent), essential for writing on plastic film

3. Plastic transparent page protectors 9-1/2 in. x 12 in. (24 cm x 30 cm), essential to prevent damage to large transparencies and to allow handling and use of transparencies without the need to wear white lint-free photographic gloves

4. Lint-free photographic gloves, mandatory when cutting transparencies from original film roll

5. Large sheets of graph paper, useful in preparing grove maps for photo interpretation.

Other Items

Other miscellaneous items such as drafting rulers, a compass, a planimeter, different color masking tapes, thin chart tapes, pencils, and pens can be selected as needed.

EXTRACTION OF INFORMATION (DATA INTERPRETATION)

The information contained in a CIR transparency is a combination of the characteristics of infrared film and an aerial overview of a citrus grove. CIR film is sensitive to light beyond the range of the human eye and records conditions of tree stress not detectable by other means (see Appendix).

Photo interpretation of CIR transparencies of citrus groves reveals a large number of differences between trees within the same block, and between trees in different areas. There have been many reports published indicating that many diseases and the effects of insect pests have been determined with CIR. While these reports may be accurate, grower photo interpreters should be aware how those determinations were made. In the photo interpretation of CIR transparencies it is only possible to see changes in tree reflectance. These changes may have been caused by a variety of reasons including:

1. Stress
2. Mechanical damage
3. Lightning damage
4. Lack or excess of water
5. Freezes
6. Weed infestation
7. Nutritional deficiencies.

Only through ground verification can the observed change from normal reflectance be confirmed and related to a specific disease or insect problem. There is a tendency to report that such a disease or problem was diagnosed with CIR photography, when that is not actually the case. Growers who know the condition of their trees and who are familiar with photo interpretation may make the assumption that changes observed in the transparencies are due to one specific cause and not another. They must also consider the additive inexactness of the objective ground verification and the objective photo interpretation, so that the total sum of the information recorded also includes ancillary knowledge from the grower's own experience. All systems for evaluating or estimating the degree of stress or conditions in citrus trees are arbitrary and range from 40 types, classes, levels, to the nine classes used in ACIMS which are listed below:

Classes

ϕ = Good--normal foliage	X = No tree
1 = Fair--some thin foliage	R = Replacement (less than 1 year old)
2 = Poor--consider removal	Y = Young tree (over 1--less than 4 years old)
3 = Worthless--remove	M = Medium.
4 = Dead tree	

Specific color and brilliance (hues and chroma) are associated with certain types of stress. Grower photo interpreters can obtain color charts from photographic, art, or paint stores which will allow them to standardize their identifications of color. In aerial color photography as well as in other color photography, the most used color standards are those of the Inter-Society Color Council and National Bureau of Standards (ISCC-NBS), the Munsell Color System, the International Commission on Illumination (Commission Internationale de l'E'clairage, CIE), colorimetric, and the CIE Spectrophotometric systems of color definition. The cost and complexity of the above systems would suggest that only portions of the system should be purchased. It may be more practical for each grower to select a simple system to standardize and expedite his own color identification. A standardized color identification system will vary in color judgement by different photo interpreters. The ability of photo interpreters to differentiate between colors should be tested at periodic intervals (Figure 18).

Analysis of Vegetation

A major benefit of analysis of ACIR photography is determination of tree condition. In making this determination the photo interpreter must be aware of a number of factors affecting tree condition and vegetation in the grove. These factors include stress, soil differences, effects of water, effects of weather, and mechanical damage. Analysis will not only provide the grower with the present status of the grove, but will also identify future problem areas.

Calibration Standards - In photo interpretation of ACIR transparencies of citrus groves, it is suggested that the photo interpreter first scan a specific block, sector, or portion of the photographic frame and select a group of trees which appear to have an even color and use this as a calibration standard (Figure 19). Once this standard group is selected it will be possible to use it as a reference when doubtful interpretations are encountered in each frame. Color changes in every frame due to sun spot and partial vignetting require calibration plots for every frame and constant comparisons with the trees observed.

the assumption that changes observed in the transparencies are due to one specific cause and not another. They must also consider the additive inexactness of the objective ground verification and the objective photo interpretation, so that the total sum of the information recorded also includes ancillary knowledge from the grower's own experience. All systems for evaluating or estimating the degree of stress or conditions in citrus trees are arbitrary and range from 40 types, classes, levels, to the nine classes used in ACIMS which are listed below:

Classes

ϕ = Good--normal foliage	X = No tree
1 = Fair--some thin foliage	R = Replacement (less than 1 year old)
2 = Poor--consider removal	Y = Young tree (over 1--less than 4 years old)
3 = Worthless--remove	M = Medium.
4 = Dead tree	

Specific color and brilliance (hues and chroma) are associated with certain types of stress. Grower photo interpreters can obtain color charts from photographic, art, or paint stores which will allow them to standardize their identifications of color. In aerial color photography as well as in other color photography, the most used color standards are those of the Inter-Society Color Council and National Bureau of Standards (ISCC-NBS), the Munsell Color System, the International Commission on Illumination (Commission Internationale de l'E'clairage, CIE), colorimetric, and the CIE Spectrophotometric systems of color definition. The cost and complexity of the above systems would suggest that only portions of the system should be purchased. It may be more practical for each grower to select a simple system to standardize and expedite his own color identification. A standardized color identification system will vary in color judgement by different photo interpreters. The ability of photo interpreters to differentiate between colors should be tested at periodic intervals (Figure 18).

Analysis of Vegetation

A major benefit of analysis of ACIR photography is determination of tree condition. In making this determination the photo interpreter must be aware of a number of factors affecting tree condition and vegetation in the grove. These factors include stress, soil differences, effects of water, effects of weather, and mechanical damage. Analysis will not only provide the grower with the present status of the grove, but will also identify future problem areas.

Calibration Standards - In photo interpretation of ACIR transparencies of citrus groves, it is suggested that the photo interpreter first scan a specific block, sector, or portion of the photographic frame and select a group of trees which appear to have an even color and use this as a calibration standard (Figure 19). Once this standard group is selected it will be possible to use it as a reference when doubtful interpretations are encountered in each frame. Color changes in every frame due to sun spot and partial vignetting require calibration plots for every frame and constant comparisons with the trees observed.

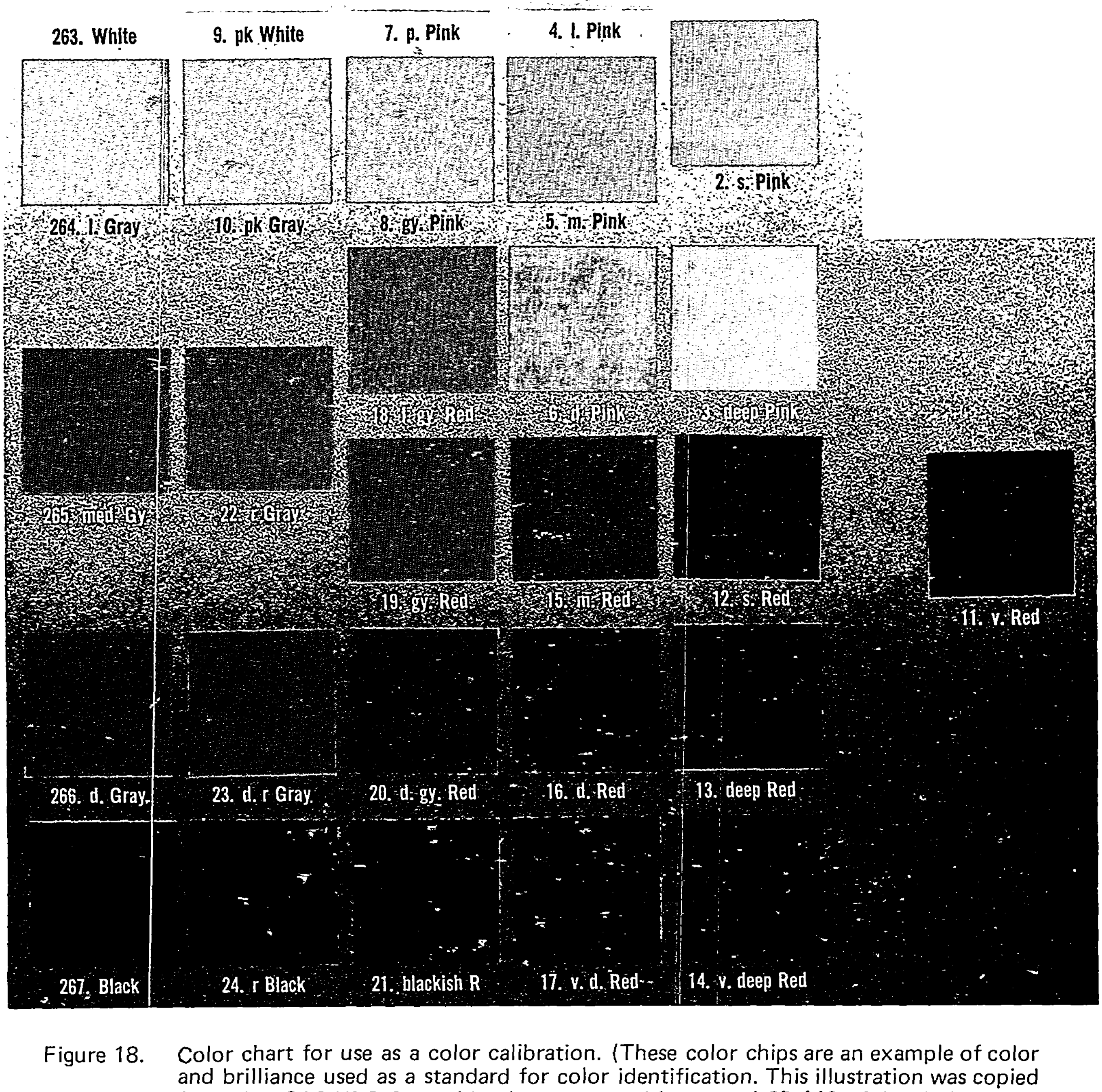


Figure 18. Color chart for use as a color calibration. (These color chips are an example of color and brilliance used as a standard for color identification. This illustration was copied from the ISCC-NBS Centroid colors presented in manual SP-440 of the National Bureau of Standards.)

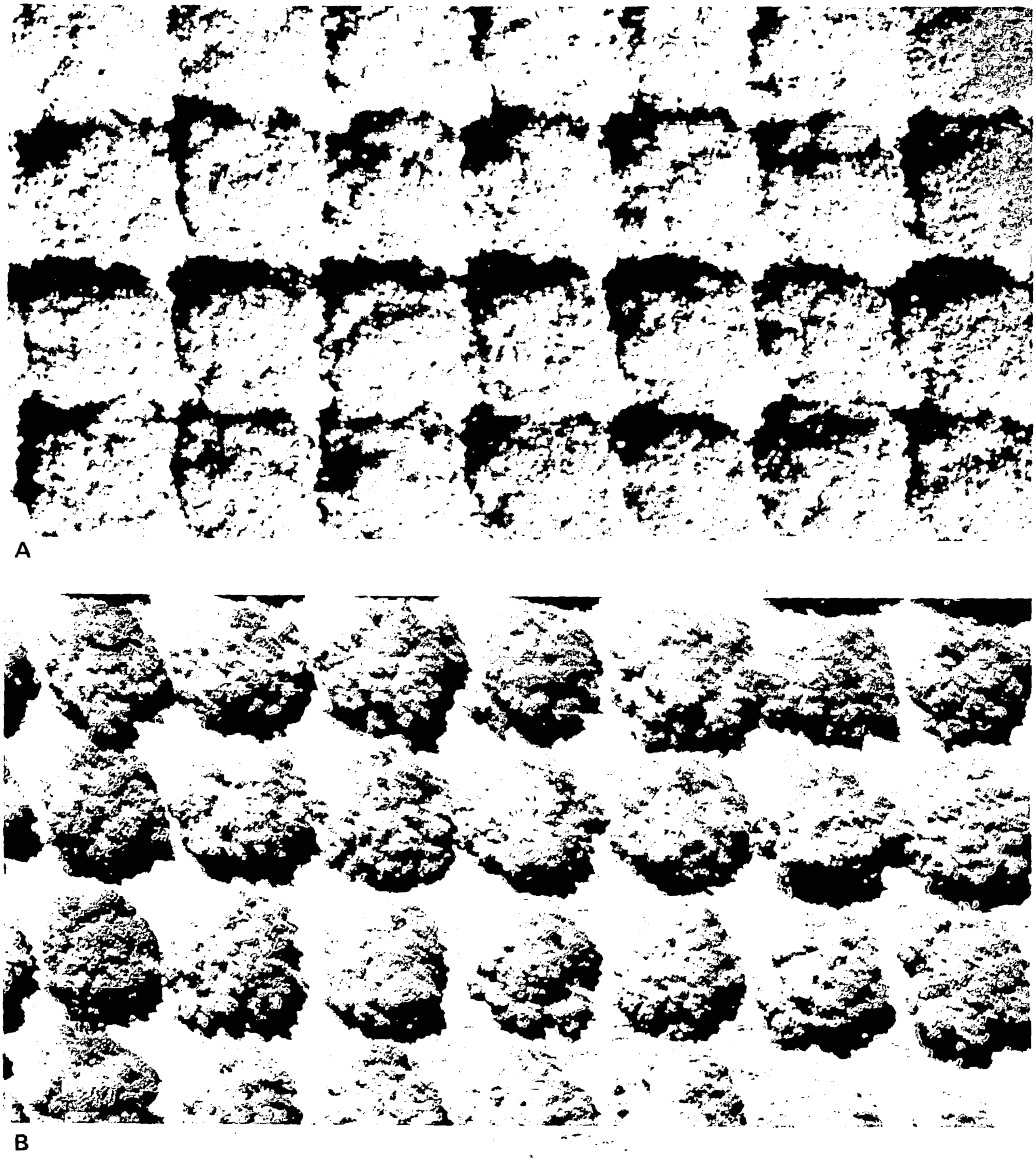


Figure 19. Calibration photograph. (A. Grapefruit trees B. Valencia trees) (Calibration plot enlargements of selected trees from an aerial CIR transparency showing the even color of grapefruit and Valencia orange trees. This photograph could be used as calibration plots for photo interpretation and ground verification.)

Stress - Stress in citrus trees may be due to normal changes or to abnormal factors such as mechanical, water, and environmental damage as well as diseases and pests. At specific growth cycles, healthy (normal) trees experience degrees of stress without detrimental effects. Perhaps the greatest stress that healthy trees undergo is when producing flowers (bloom) and young leaves (flush) during the spring growth. Experience gained during the ACIR experiment indicated that it is at this time that it is easiest to distinguish the health of a tree both on the ground and on film. The difference between normal and abnormal stress can be observed at other times throughout the year; however, it is much more difficult to see. The unhealthy trees cannot withstand normal stress and lack the ability to produce flush as fast as or at the same time as healthy trees. In ACIR transparencies, unhealthy trees vary in red color proportionally to their degree of health. Abnormally stressed trees that have not produced a flush have only old foliage on their crowns. The crowns of such trees will not be red but change from light blue/purple to blue depending on the degree of abnormal stress and will contrast greatly with the young leaves of the trees in flush. The reflectance of the older leaves is recorded on CIR film as a much darker hue of red/pink, depending on the color balance of the transparency.

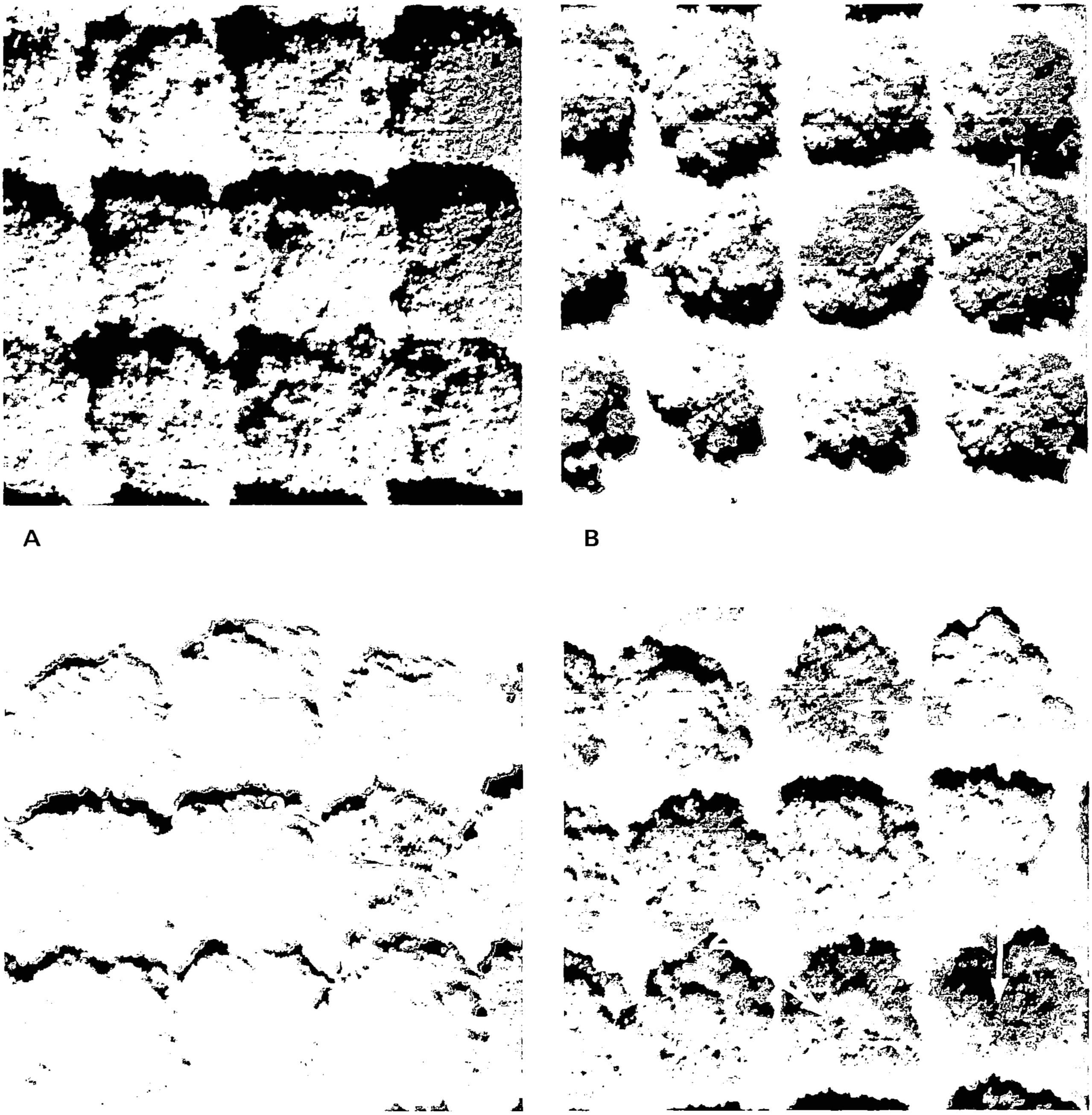
An arbitrary method of measuring tree size by canopy diameter was developed to measure or estimate tree canopy size (Figure 9) and determine in which category the tree belongs (young, medium, or large). Efforts have been made to develop a light-measuring device to determine canopy density, but few are in use since they are not very accurate (Appendix).

Diseases, Insects, and Nematodes - Diseases, insects, and nematodes have a considerable effect on the degree of abnormal stress in specific trees, and constantly affect management decisions such as spraying practices and replanting programs. Photo interpretation of varying degrees of stress is not difficult between the distinctly different ϕ class (healthy, zero percent 'ost canopy) and the No. 3 (dying, 75 percent lost canopy), and No. 4 (dead, 100 percent lost canopy) trees. It is more difficult to distinguish between class No. 1 (25 percent lost canopy) and class No. 2 (dying, 50 percent lost canopy) trees. The greatest percentage of photo interpretation errors are made between these two classes (Figures 20 and 21).

Diseases - The effect of the diseases of citrus trees is easily seen on ACIR photographs rather than the disease itself. While at the present time it is impossible to identify citrus diseases on CIR film, it is believed that with improvements in remote sensing technology it will be possible to accomplish this. Foliar and root diseases cannot be identified unless they are severe enough to defoilate branches or the entire tree. Diseased trees can be distinguished from healthy trees in part because the ground reflectance is more readily observed.

Insects - Citrus tree insects, like diseases, are not easily observed from aerial CIR photographs. The effects of the insect, unlike those of diseases, are much more easily observed on citrus foliage. For example, the excessive production of feces by citrus insects allows the growth of a fungus (Capnodium citri Berk. and Desem.) to develop a black coating (matted strands of filaments of the fungus) which is called sooty mold (Figures 22 and 23). The effect of other types of scale insects have been distinguished with CIR in Texas by Hart et al. (ref. 8).

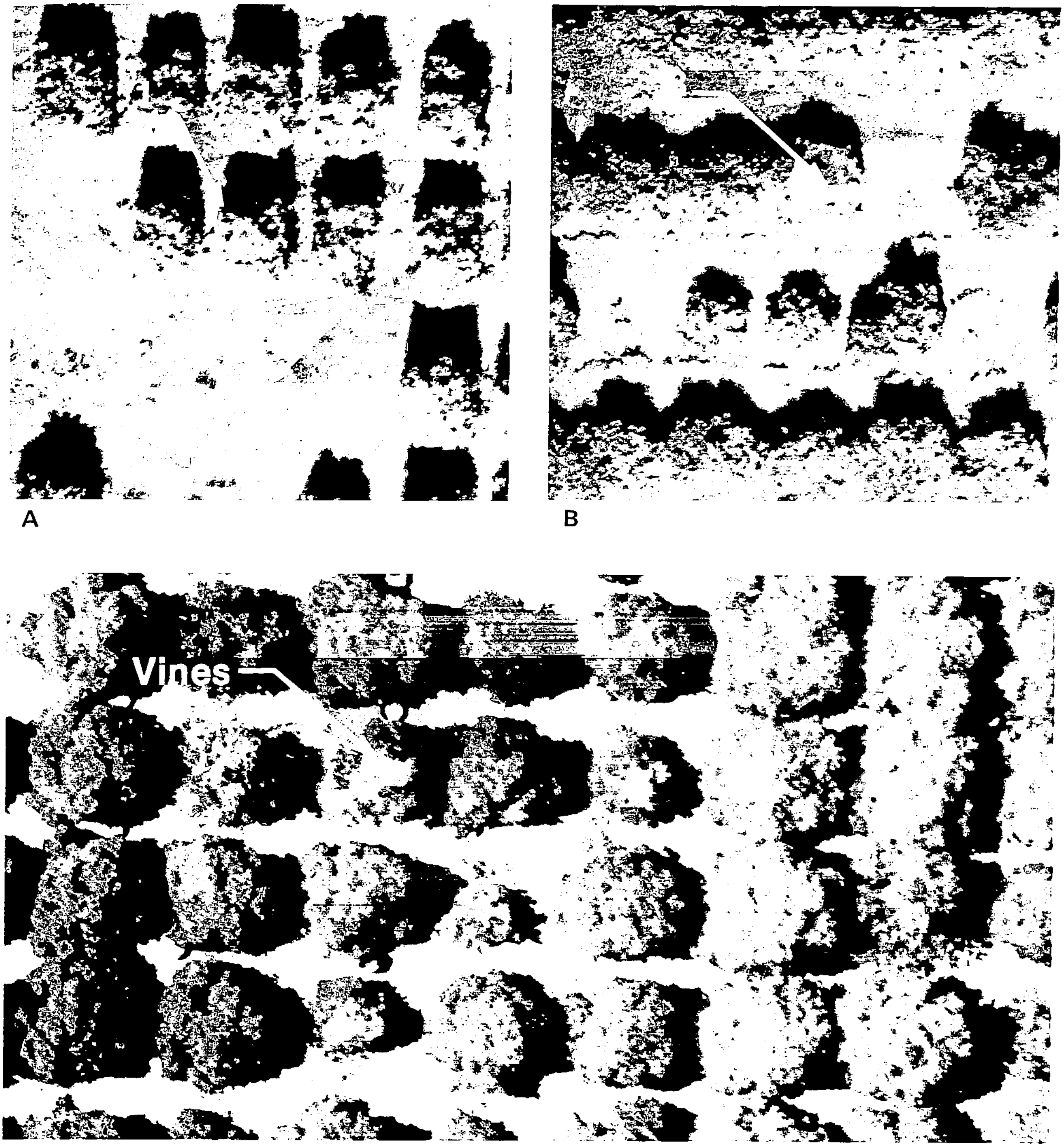
Nematodes - Nematode problems have been serious in some citrus growing areas. It is possible to delineate and quantify the damage due to nematode feeding by associating loss of reflectance with tree health, but it is not possible to specifically identify nematodes with CIR film. In quantifying the damage by nematodes to citrus trees, the changes in reflectance, and the severe loss of trees



A B

C D

Figure 20. Enlargements of tree conditions (ϕ, 1, 2, 3, and 4). (Enlargement of an aerial CIR transparency of a grove in Polk County, Florida, taken during the spring season. A. Calibration plot of grapefruit show even-color foilage. B. Valencia orange trees with a No. 1 tree. C. A No. 2 grapefruit tree with a hole. D. A group of Valencia orange trees in No's. 2, 3, and 4 condition.)



A

B

C

Figure 21. Enlargements of tract-type grove showing vines, grasses, and weeds. (Enlargements of aerial CIR transparencies from different groves taken during the summer (July 11, 1978). A. Enlargement of a tract-type grove showing: (1) dead tree covered with vines and (2) grass covered ground; B. A second dead tree (3) covered with different vine types and weeds; C. Vines growing on top of trees under different stress conditions.)

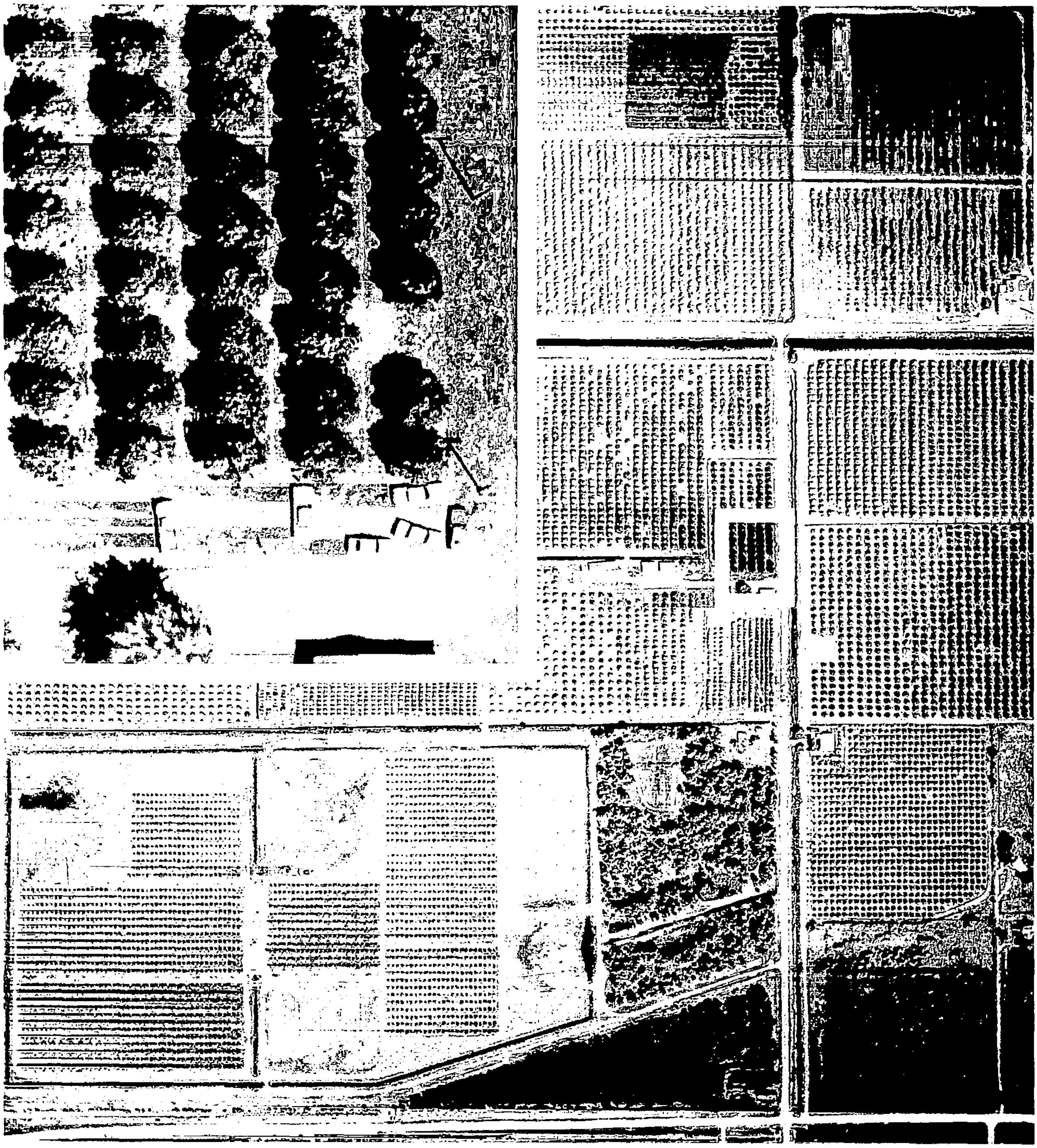


Figure 22. Fort Pierce Agricultural Research Center (ARC) sooty mold plot and enlargement. (An aerial CIR photograph of the citrus plots at the ARC, Fort Pierce, Florida, showing the location of a sooty mold (Capnodium citri Berk. & Desm.) test plot and an enlargement of the plot showing various degrees of blackened trees also partially covered with vines. Scale: 1 in. = 500 ft.)

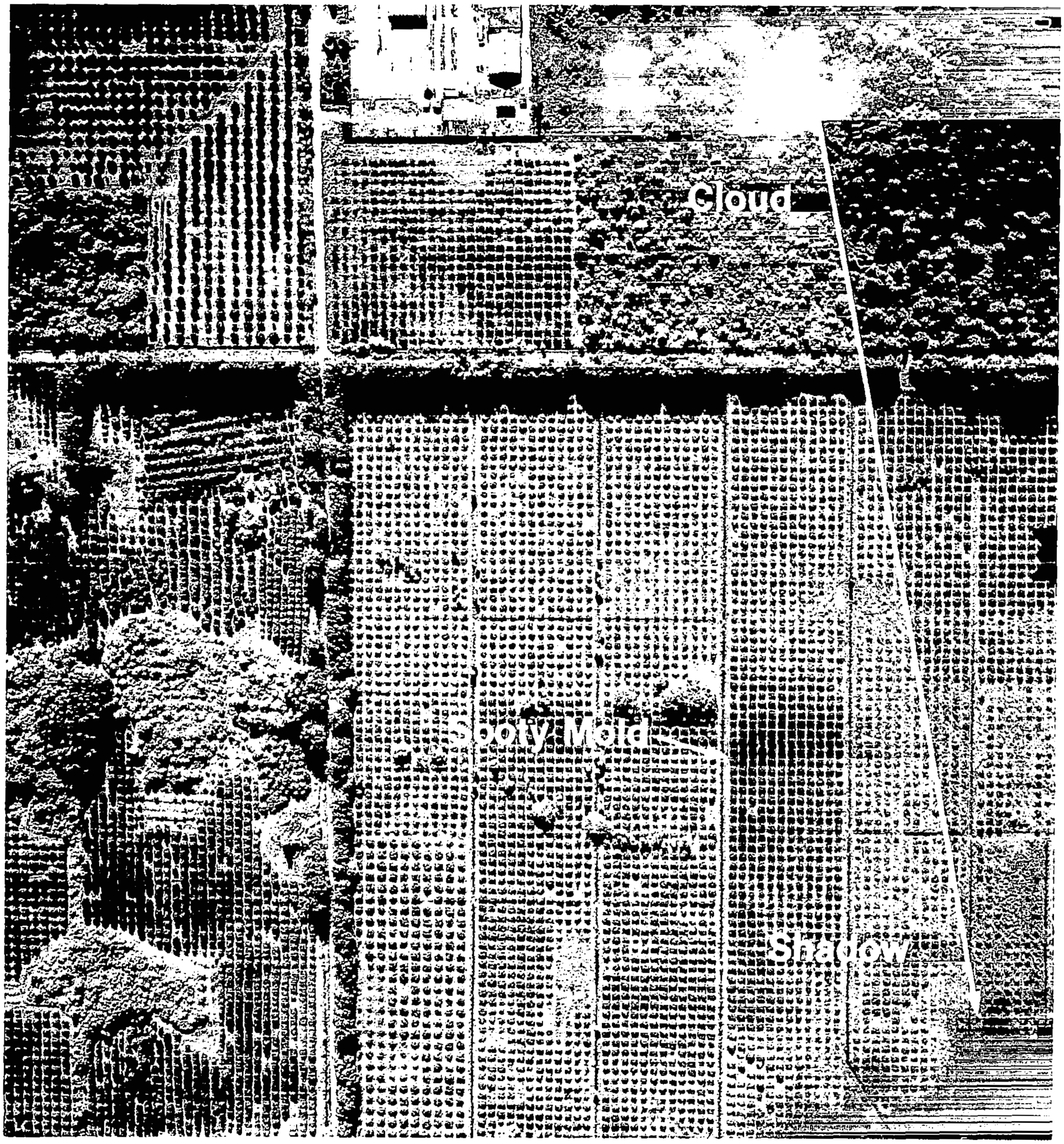


Figure 23. An aerial CIR photograph of Kennedy Space Center (KSC) showing sooty mold and clouds. (A summer (July 11, 1978) aerial CIR photograph of an orange grove at KSC showing the growth of grass, cloud interference, and sooty mold (Capnodium citri Berk. & Desm.) on some of the trees. Scale: 1 in. = 500 ft.)

in a pattern suggests nematode infestation. Once the suspected infestations are verified by ground survey, a greater degree of separation of health-infestation may be possible (Figure 24).

Rating of Tree Condition - Tree condition rating in ACIR transparencies is essentially a series of constant comparisons between the colors of a group of trees of an even color (calibration trees) and the trees under consideration. The emulsion of the CIR film has been prepared so that the visible colors in the transparency are not the natural colors of the trees, but are instead false colors having greater contrast than do the natural colors. Healthy vegetation on CIR film appears red instead of green, and abnormally stressed vegetation varies from a green to a blue color.

Tree size is also considered in photo interpretation of tree condition because in many cases there are trees of different sizes with different conditions of stress (Figure 25).

Class ϕ--Healthy - A healthy, normal, large tree, with no loss of canopy, is classified as a ϕ tree. The canopy of a ϕ tree will have an even red color throughout without any shadows. Its color can easily be matched to surrounding trees and the set of trees chosen as a standard in the calibration group (Figure 20).

Class 1--Slight Decline - Trees in this class have a slight off-red color when compared to ϕ trees or the calibration group. There may be some dark blue holes or areas in the canopy and tips of branches will be defoliated. Occasionally, the entire tree will be a dark red without holes or twig defoliation with 25 percent of the canopy lost (Figure 20).

Class 2--Moderate Decline - Trees with loss of foliage (50 percent lost canopy) and considerable twig die-back as well as some large holes in the canopy are No. 2 trees. They range in color from light blue to greenish-grey under different conditions. Particular records should be kept of these trees, as they may probably die within 10 to 12 months after the photographic mission (Figure 20).

Class 3--Severe Decline - These trees may have scattered pink areas in a canopy that is mostly greenish-grey as a result of severe twig and branch dieback (75 percent lost canopy). A number of dark holes may be visible due to the reflectance of soil under the canopy coming through the severely defoliated tree. In most cases these trees will be removed by growers once they are located in the grove (Figure 20).

Class 4--Dead Trees - Well-managed groves will seldom have dead trees; however, should they be present, the large bare branches are readily visible and a dark blue color will be present in the transparency because the tree will have lost 100 percent of its canopy. Reflectance from bare ground can be readily observed, particularly if there are patches of grass under the dead tree (may be camouflaged by vines) (Figure 20).

Undesirable Vegetation - Well-maintained citrus groves are continuously cultivated to prevent undesirable vegetation from invading areas near or on the trees that might interfere with normal fruit production. Some of the undesirable vegetation observed on ACIR photography may be:

1. Water sprouts from rootstock, visible as off-color branches on the sides of the tree or coming through the center of the canopy. They are usually not very large and can easily be missed (Figure 21).

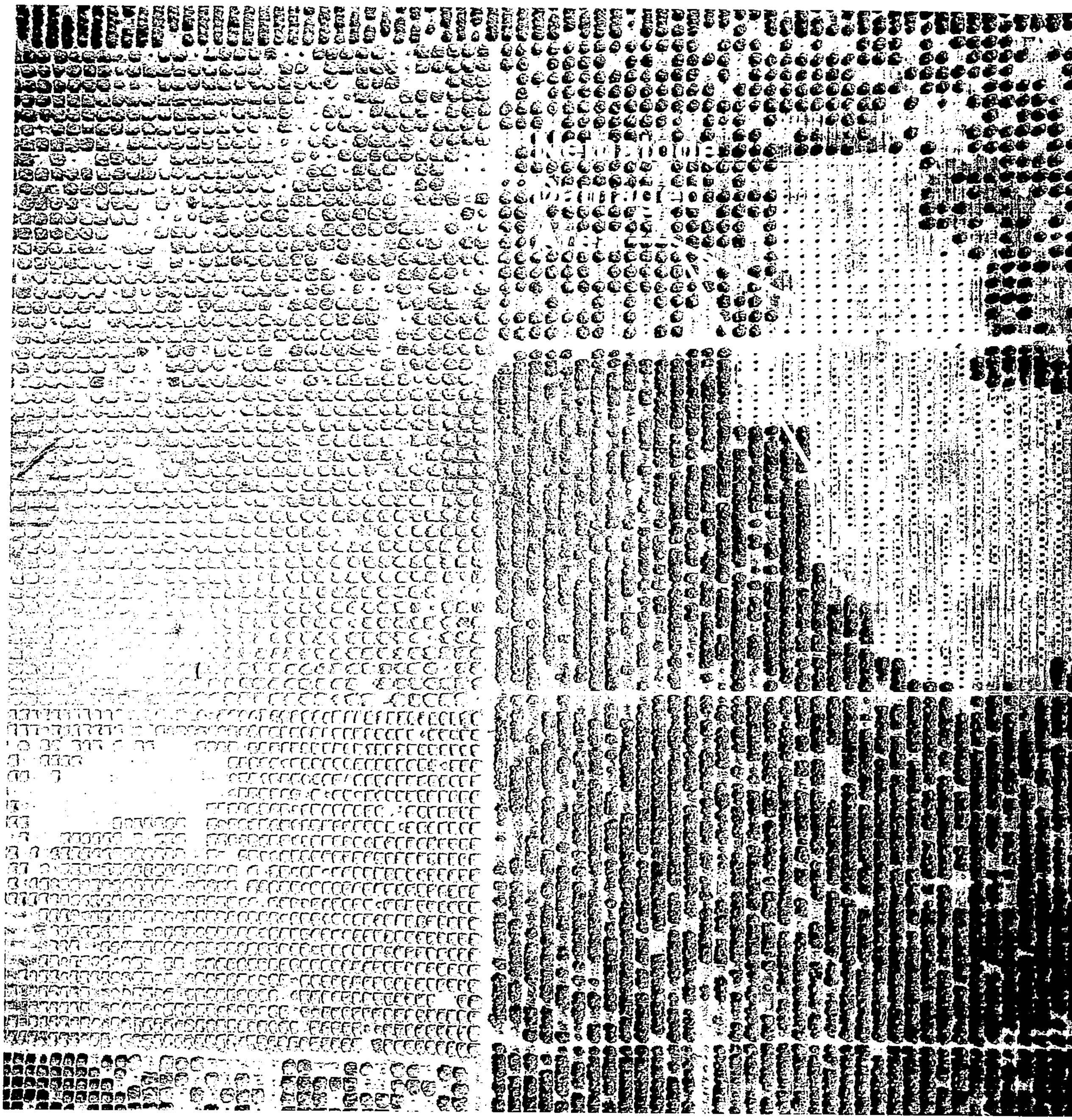


Figure 24. Replanted area due to nematode damage. (A spring (April 11, 1978) aerial CIR photograph of a grove in Polk County, Florida, showing a large area of orange trees destroyed by nematode damage and recently replanted. The area is clearly visible on the right side of the photograph. Scale: 1 in. = 333 ft.)

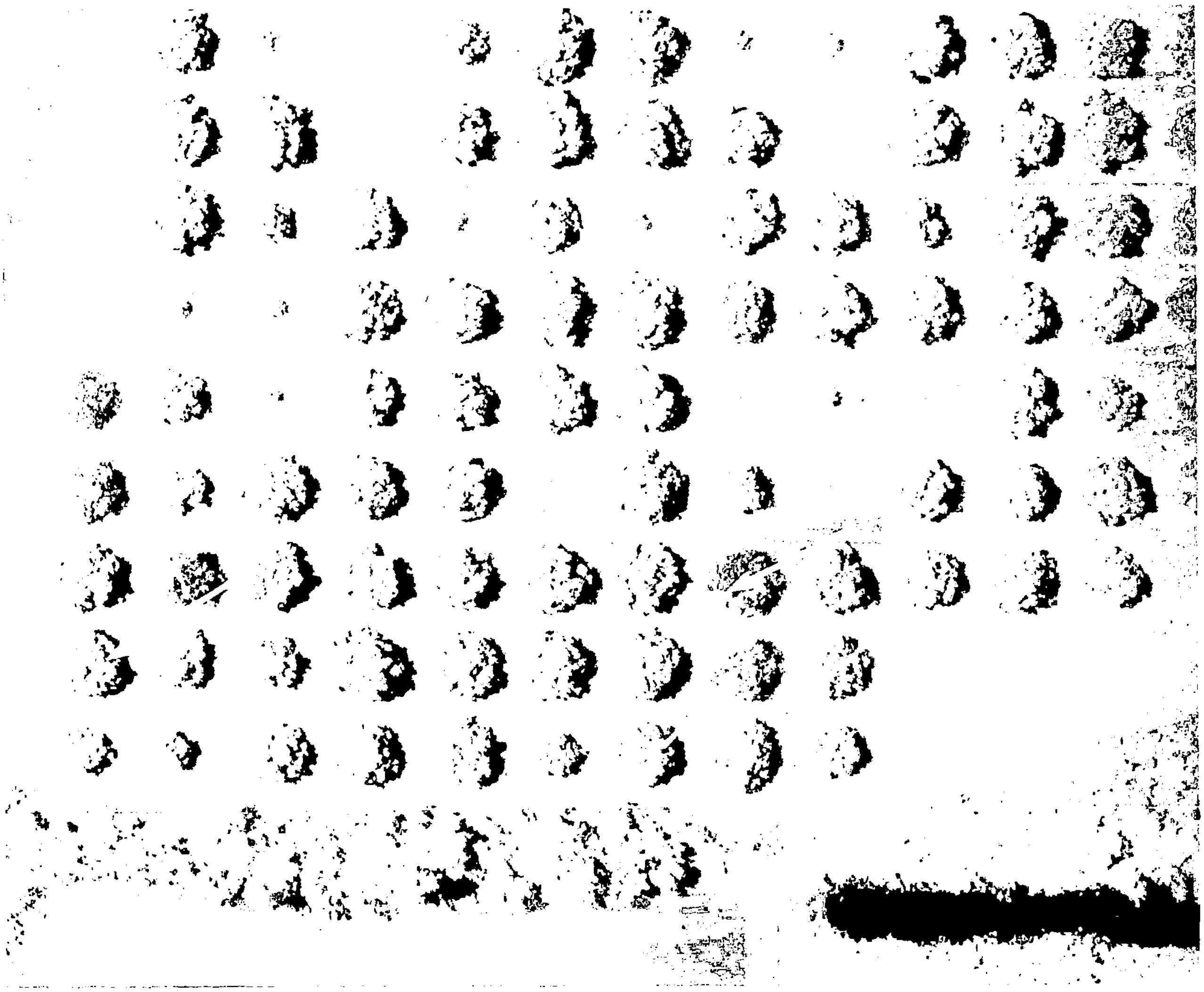


Figure 25. Enlargement of tree sizes. (Enlargement of an aerial CIR transparency of a grove in Polk County, Florida, taken during the spring (April 11, 1978). Different sizes of Hamlin orange trees can be observed under different conditions of stress varying from ϕ (healthy), to No. 1 (25 percent lost canopy), to No. 2 (nearly 50 percent diseased foliage).)

2. Other trees, such as the avocado (Persea americana Mil) which have larger crowns and a different coloration than the citrus trees, may be observed at the sides or through the canopy of the citrus trees (Figures 26, 27, and 28).

3. Vines, sometimes difficult to see, but generally having an off-pink discoloration are readily separated from the darker pink citrus tree canopy. Occasionally, some vines have a greenish-grey appearance on top of the citrus canopy. It is best to scan surrounding trees to check if vines are also present on their tops (Figures 21, 26, and 28). Vine infestation is best observed in summer photography.

4. Grasses, sometimes difficult to separate from citrus foliage, particularly during the summer months. In fact, grass reflectance is so severe and distracting (confounding) in summer aerial photography, that summer aerial photography is strongly discouraged except when photographing for vine infestation. Should summer photography be needed, it is highly recommended that growers mow or apply herbicide to their groves before any photography is carried out (Figure 11).

Soil Differences

Soil differences are easily detected in ACIR photography. These differences may be very distinct with sharp delineations or they may be gradual. Differences in tree growth on different soil types may be easily observed in some areas such as one site in St. Lucie County near Fort Pierce, Florida, where a muck pocket has the best growing and least blight diseased trees (Figure 29). The B&W copy of an ACIR photograph of a site in Polk County near Lake Alfred, Florida, clearly shows the border lines between the white sand in the center of the photograph and the darker soil at the top (Figure 10).

Effects of Water

Seepage of water through grove soils is easily visible on CIR film. The main effects of water on groves can be observed in areas that are irrigated either by rainbird guns mounted on tractors or have a permanently installed sprinkler system. Moistened or wet soil will appear as a deep blue color. It is possible to see the areas that are covered by the sprinklers and locate faulty sprinklers (Figure 12). The increased moisture in grove soil can be observed even after a tractor mounted rainbird has moved on (Figure 13).

Plowing or cultivating will change the reflectance of the dry surface soil and the soil color will appear different due to the turned over moist soil. A similar effect results when a tractor goes over dry sand, the tracks of the tractor are readily visible (Figures 26 and 27).

Effects of Weather

Frost damage occurs in Florida at varying winter periods. While ACIR has shown the ability to detect frost damage, no conclusive experiments have been carried out to make accurate determinations. Wind damage can usually be observed on ACIR transparencies as well as any other mechanical damage which may occur. Lightning damage is a more difficult weather effect to photo interpret,

Figure 26. Winter photography of a grove in Polk County with avocado enlargement. (A winter (February 11, 1978) aerial CIR photograph of a grove in Polk County, Florida, showing the lack of contrast between orange and grapefruit varieties, and the different reflectance of an avocado tree. An enlargement of the area surrounding the avocado tree (small square) shows vine infestations and bare branches on tops and sides of trees. (Note visible tractor tracks due to moisture difference.) Scale: 1 in. = 333 ft.)

Figure 27. Spring photography of a grove in Polk County with avocado enlargement. (A spring (April 11, 1978) aerial CIR photograph of a grove in Polk County, Florida, showing the high contrast between grapefruit trees and orange trees in flush. An enlargement of an avocado tree shows little or no contrast between its foliage and the surrounding orange trees. (Note visible tractor tracks due to moisture difference.) Scale: 1 in. = 333 ft.)

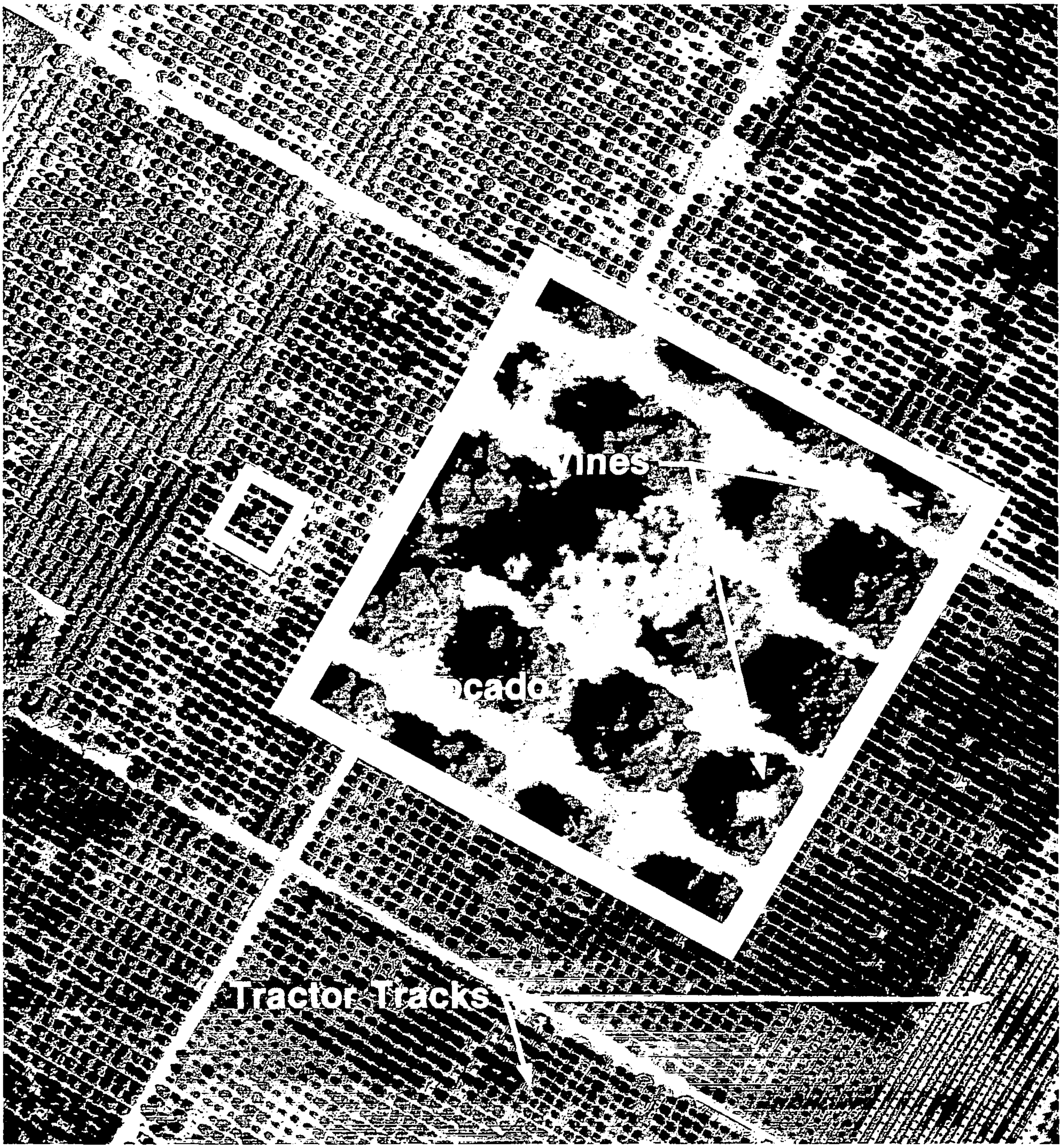


Figure 28. Summer photography of a grove with avocado enlargement. (A summer (July 11, 1978) aerial CIR photograph of a grove in Polk County, Florida, showing vines growing on top and within the canopy of the trees. The avocado tree shows contrast between its foliage and that of surrounding orange trees. Scale: 1 in. = 333 ft.)

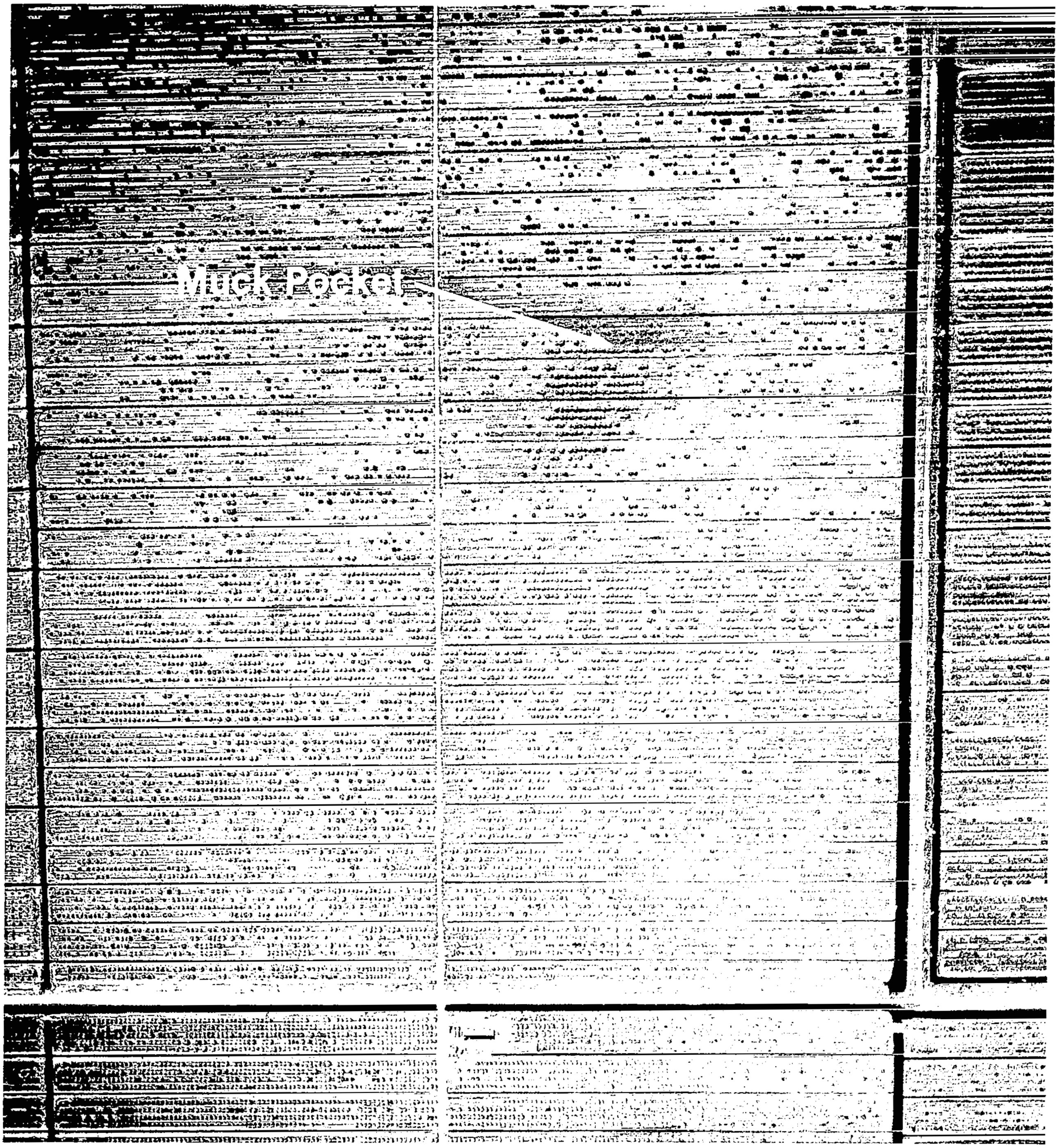


Figure 29. A St. Lucie County grove with muck pocket showing healthy trees. (A spring (April 11, 1978) aerial CIR photograph of a grove in St. Lucie County, Florida, showing a muck pocket in the center of the photograph with healthy growing trees among sandy areas with considerable blight diseased trees. Scale: 1 in. = 500 ft.)

but it can be frequently observed where 20 to 30 trees have been killed at once. Clouds over the photographic site can be devastating and will cause termination of a photographic mission whenever they become serious over the target. Clouds have a greater effect on CIR film that on all other types of film. The effect of clouds can be observed on a summer photograph in Figure 23.

Mechanical Damage

Mechanical damage from hedging and topping is a most difficult type of damage to detect from ACIR transparencies. Trees that have had severe mechanical damage can be observed as single dead trees among healthy ones. Damage less than lethal would probably be incorporated into tree condition determination and usually would be established by ground verification (Figure 30).

SEASONAL GROWTH EFFECTS

Differences between types of citrus trees (orange and grapefruit) vary according to the season, and were best observed in ACIR photography taken during the spring (April) season (Figure 27). Although these differences are not as obvious in winter (February) and summer (July) photography (Figures 26 and 27), they can be detected. Weeds and other vegetation, such as avocado trees, could not be readily distinguished from orange trees in the spring photography (Figure 27), but was readily observed in the winter (Figure 26) and summer (Figure 28) photography. Vines growing on top of orange trees were easily differentiated from dead branches by comparing winter and summer photographs. Dead branches were easily observed in the winter photography, while the vines could best be observed in the summer photography. The importance of the optimum season for photographing a particular type of vegetation cannot be overestimated.

GROUND VERIFICATION TECHNIQUES

Confirmation of the accuracy of photo interpretation decisions is made by verifying on the ground those areas selected as calibration sites in each transparency, as discussed in Analysis of Vegetation (page 39) (Figure 19). Ground verification of the number and distribution of calibration sites should only be sufficient to establish a satisfactory level of confidence in photo interpretation.

Two suggested approaches to partially eliminate some of the inexactness of ground verification is to carry out arbitrary determination of tree health by:

1. One individual daily verifying the same site repeatedly over a period of 7 to 10 days

2. Many individuals verifying the same site repeatedly in 1 or 2 days.

It is important that an enlarged B&W print of the grove area, including the calibration test sites, be available for optimum orientation and to eliminate mapping problems. Ground verification should be made by not following the same pattern of travel. In fact, it is recommended that starts should be made at different rows, reversed, and mixed as often as possible. Repetitive verification results should be compared to determine the percent of variability in grading tree health (Figure 31).

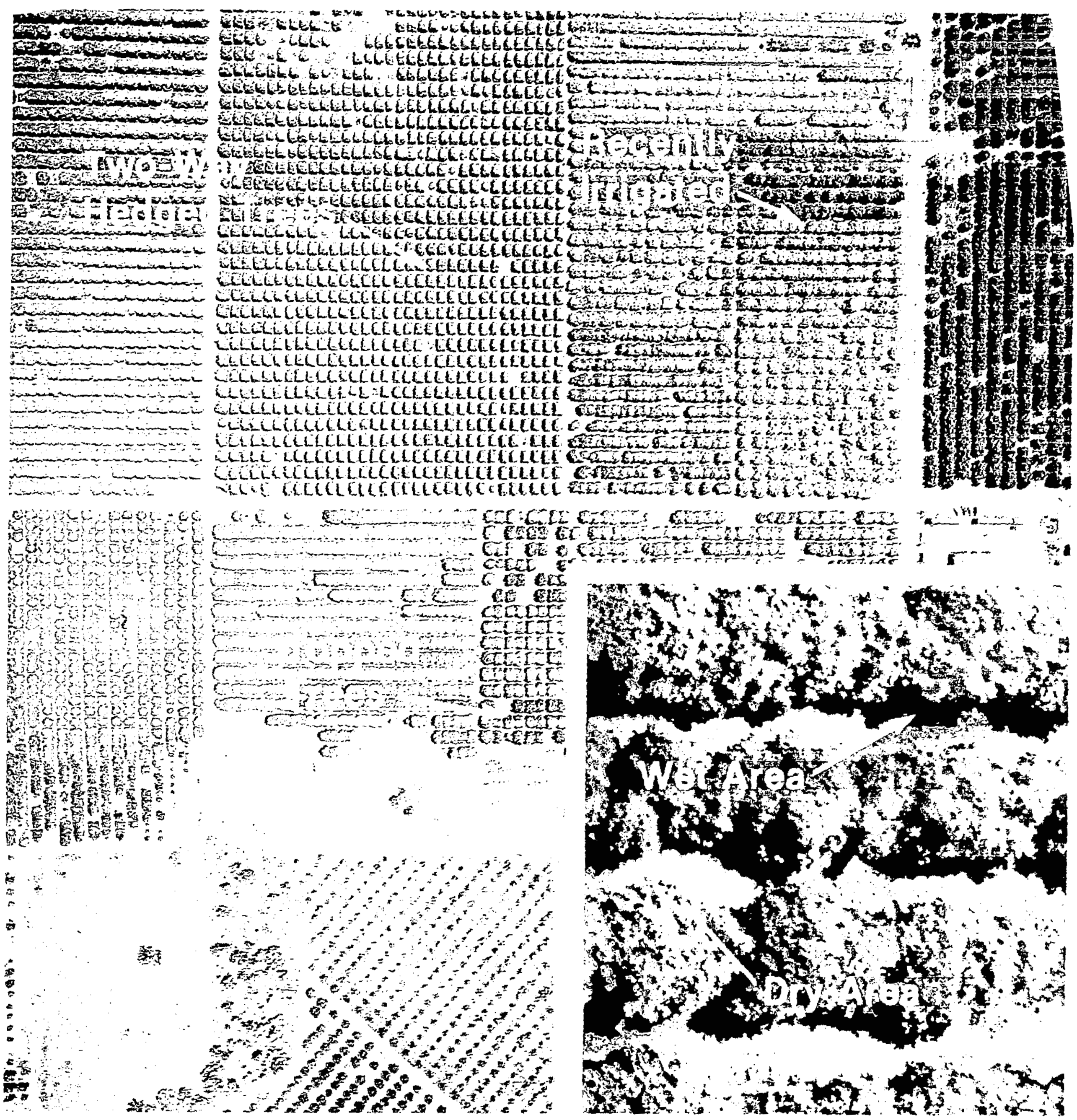


Figure 30. Irrigation effects and mechanical damage from hedging and topping. (A spring (April 11, 1978) aerial CIR photograph showing the effect of topping orange and grapefruit trees. Two-way hedging allows greater amounts of light to penetrate the grove. An enlargement of the irrigated grove shows the dry areas beneath the trees. Scale: 1 in. = 333 ft.)

PHOTO INTERPRETATIONS FROM CIR TRANSPARENCIES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
INTERPRETER 1	0	0	0	0	X	0	0	0	0	0	0	0	1	0	1	X	0	1	0	0	0	1	2	1	0	X	X	0	2	R	R	X
2	0	0	0	0	Y	0	0	0	0	0	0	0	1	0	1	X	0	2	0	0	1	3	0	0	Y	X	0	2	Y	Y	X	Y
3	1	1	0	1	X	1	1	1	1	1	0	2	1	2	X	1	2	1	1	1	1	1	0	X	R	1	2	Y	Y	X	1	1

GROUND VERIFICATIONS FROM CITRUS GROVES

INTERPRETER 1	0	Y	0	1	Y	0	0	1	0	0	0	0	X	1	X	X	0	X	1	1	2	0	0	0	X	Y	0	X	R	Y	Y	0
2	0	Y	0	1	Y	1	0	1	0	0	0	0	X	0	X	X	0	X	0	1	2	X	1	0	X	Y	1	X	R	Y	Y	0
3	0	Y	0	0	Y	0	0	0	0	0	0	2	X	0	X	X	0	X	0	0	2	X	0	0	X	R	0	R	R	R	R	0

COMPARATIVE PHOTO INTERPRETATIONS AND GROUND VERIFICATIONS

TREE CONDITION OR SPACE STATUS	SYMBOL	PHOTO INTERPRETER 1				PHOTO INTERPRETER 2				PHOTO INTERPRETER 3			
		PHOTO INTERPRETATION		GROUND VERIFICATION		PHOTO INTERPRETATION		GROUND VERIFICATION		PHOTO INTERPRETATION		GROUND VERIFICATION	
		NO.	%	NO.	%	NO.	%	NO.	%	NO.	%	NO.	%
HEALTHY	0	18	56.2	14	43.7	18	56.2	12	37.5	3	9.4	17	53.1
MISSING	X	5	15.6	6	18.7	3	9.4	7	21.8	4	12.5	6	18.7
REPLACE-MENT	R	2	6.3	1	3.1	0	0.6	1	3.1	1	3.1	5	15.6
DISEASED	1, 2, 3, 4	7	21.8	6	18.7	6	18.6	7	21.8	22	58.7	2	6.3
YOUNG	Y	0	0	5	15.6	5	15.6	5	15.6	2	6.3	2	6.3
		32		32		32		32		32		32	

Figure 31. Comparative observations work sheet. (Worksheet example of comparative observations between individuals rating trees from aerial CIR transparencies and repeatedly verifying the same trees on the ground. The sums of results indicate the percentage of total classifications chosen for each category.)

Comparison by many individuals can be made by substituting the number of individuals for the different daily tree gradings and the percent variability compared among individuals. Experienced citrus field specialists usually have little problems with analysis of citrus vegetation present in ACIR photography. It is suggested that all individuals verify and compare their differences in grading and discuss their reasons for their choices of tree health. The greater the interaction between the individuals in ground verification the greater the accuracy they will have in photo interpretation.

DATA RECORDING AND PROCESSING

The processing of photo interpreted data from ACIR photographs of citrus groves is a laborious task. It must be carefully planned and executed. Ground verification and photo interpretation are largely subjective arts and very difficult to quantify objectively. Therefore, accuracy of results is strongly dependent on the experience and expertise of the ground verification specialist and the photo interpreter. Errors are minimized when the ground specialist and the photo interpreter are the same individual. Technical assistance by field experts will enhance and extend the usefullness of the ground specialist/photo interpreter, but in every operation there must be at least one such well trained individual to insure success. Preparatory steps for the recording of data were described in the Grower Film Labeling and Frame Registration paragraph on page 30 in this handbook.

GROVE GRID/CELL DESIGN

The grid/cell developed for rapidly and repeatedly locating individual trees in any photograph or transparency is the most important component of ACIMS. A grid/cell map of a grove can easily be prepared by superimposing a transparent paper over a photograph or transparency and delineating cells at specific intervals to make a grid. Size of cells will depend entirely on tree spacing, type of planting (tract or bed), and grower preference (Figure 32). The type of cells selected for use in tract groves of Polk County was an eight tree by eight tree cell, with a total of 64 trees planted at a spacing of 30 ft (9.1 m) between trees. The grid/cell system can be adapted to either small, medium, or large groves.

MANUAL RECORDING SYSTEMS

Analysis of photo interpreted data for small acreage is not difficult and can be accomplished with tabular data grids based on graph paper and transparent overlays. A number of paper or ruled grids may be used to maintain proper tree registration and as aids in keeping records. The following are two types of systems that expedite data recording.

Overlay Processing

Transparent overlays are prepared by tracing the grid or row/tree numbers on thin paper over B&W prints or by copying with transparent copying films such as the ones made by Thermofax, 3M

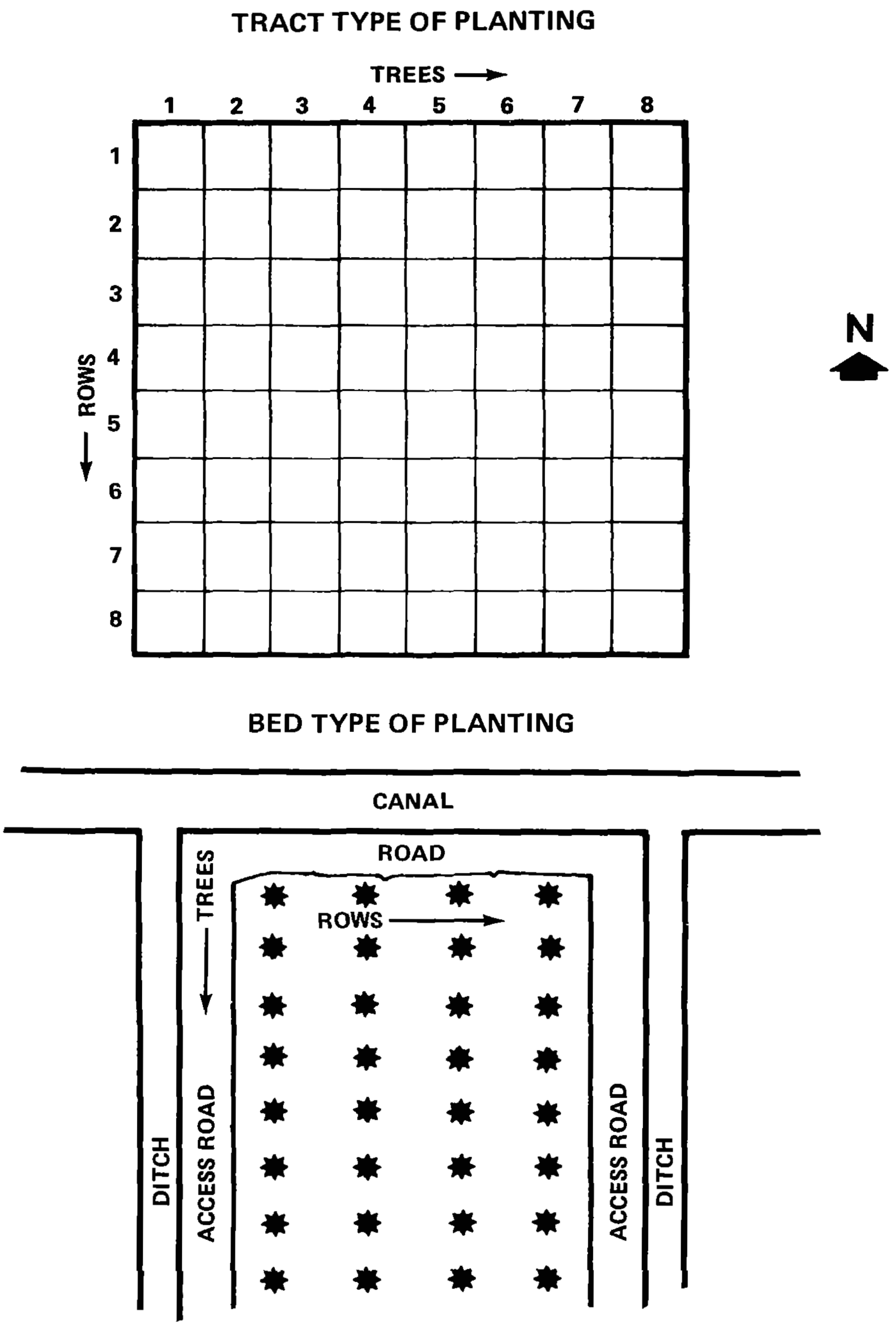


Figure 32. Schematic diagram of a grid/cell system adaptable to tract or bed type of planting. (Schematic diagram of a grid/cell system showing a tract type of planting divided into 64 cells (8 x 8) and a bed type of planting divided into 32 cells (4 x 8). This system is adaptable to either type of planting.)

Corporation, or Xerox. Once the grid formats have been prepared the desired data may be recorded on the overlay. The overlay may then be taken off and copied on paper with a copying machine. Care must be taken to record data with black pencils, as blue colored pencils or ink will not be copied by most duplicating machines.

Window Overlay System

A modification of the overlay system can be made by preparing a colored transparent grid overlay of the transparency and cutting one of the central cells out, so that a mask would cover all cells not being photo interpreted and cause the central cell to be distinctly enhanced (Figure 33). The data from the transparency can either be recorded as a list or in a map format, depending on the growers choice. It is possible to speed up recording through the use of calculators, if only total numbers are desired.

COMPUTER SYSTEMS

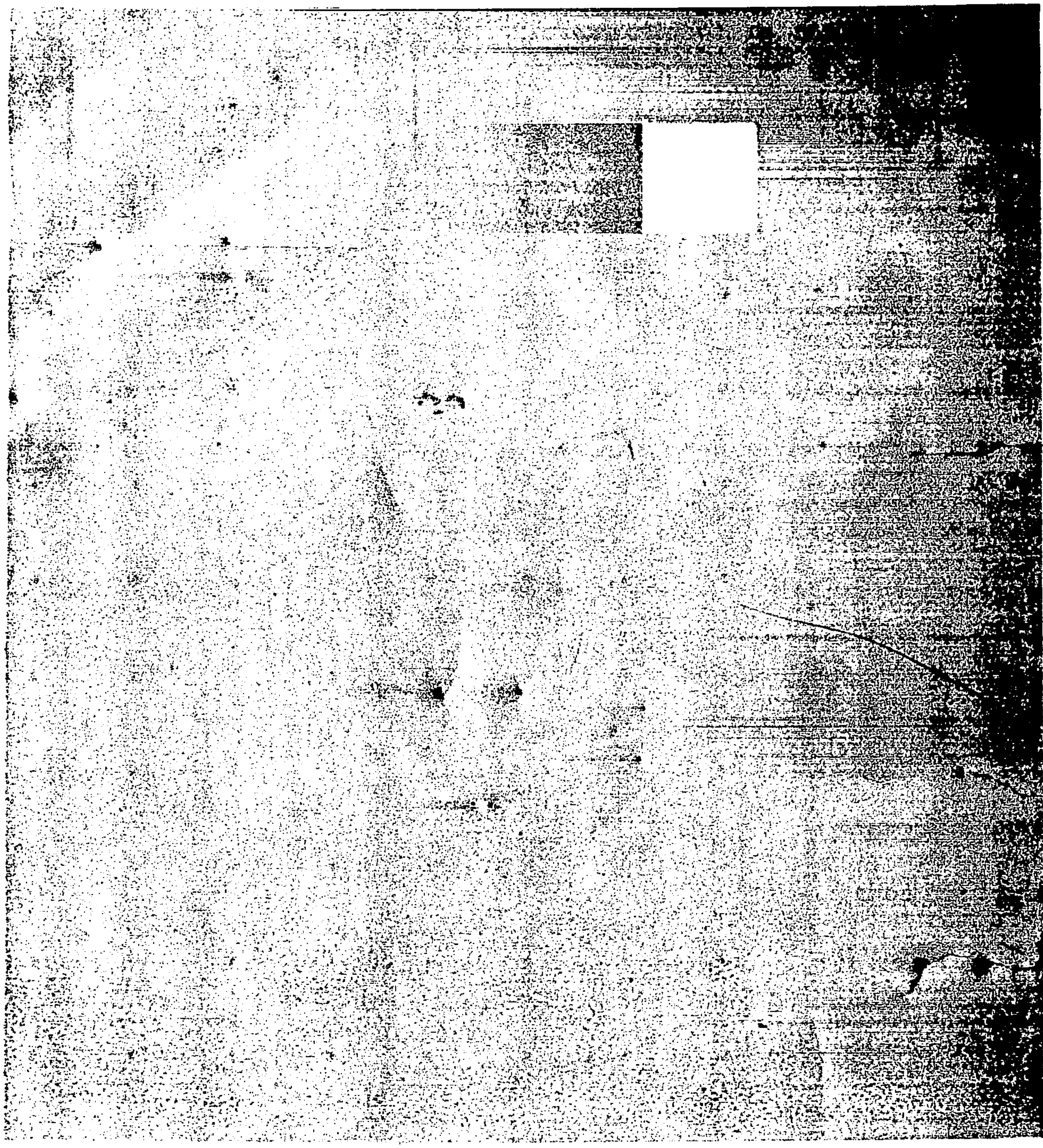
The use of the cell system has made it possible to adapt ACIMS to a computer recording format. A prototype computer program based on the photo interpreted data cell system was developed (as an example) for recording data from a citrus grove in Polk County, Florida (Figure 34). The computer program was also modified to process data from ACIR transparencies taken of citrus groves planted with the bed type of planting system used in south Florida (Figure 29).

The prototype computer program is in the Agricultural Research and Education Center (AREC) Lake Alfred, Florida, General Automation SPC 16/65 minicomputer and is presented in FORTRAN language. It can be adapted to many other computer languages and planting systems. The program was developed to produce total counts per specific classification group (grove, block, row, tree, number, and beds), if needed. It also makes it possible to obtain a list of the exact location of all trees (by cell, row, and tree numbers) as well as a printout of the entire grove showing all the tree conditions photo interpreted from the CIR transparency. Symbols selected for writing tree condition in lists or field verification maps had to be modified slightly for computer use to simplify printout appearance (Figure 34).

Advances in electronic manufacturing techniques have reduced production cost of minicomputers or microprocessors to a level where it is practicable for small and medium growers to own them. New adaptations of microprocessors such as digitizers and voice activated systems may be additional breakthroughs that will accelerate the use of microprocessors by growers and grove maintenance companies. The application of computers by growers for payroll and budget recordings is increasing, so their utilization for storage, compilation, and retrieval of grove data is additional justification for their use.

AUTOMATED PHOTO INTERPRETATION/ANALYSIS

A large number of organizations and individuals have expended considerable effort toward developing automated systems for photo interpreting transparencies by densitometry or image



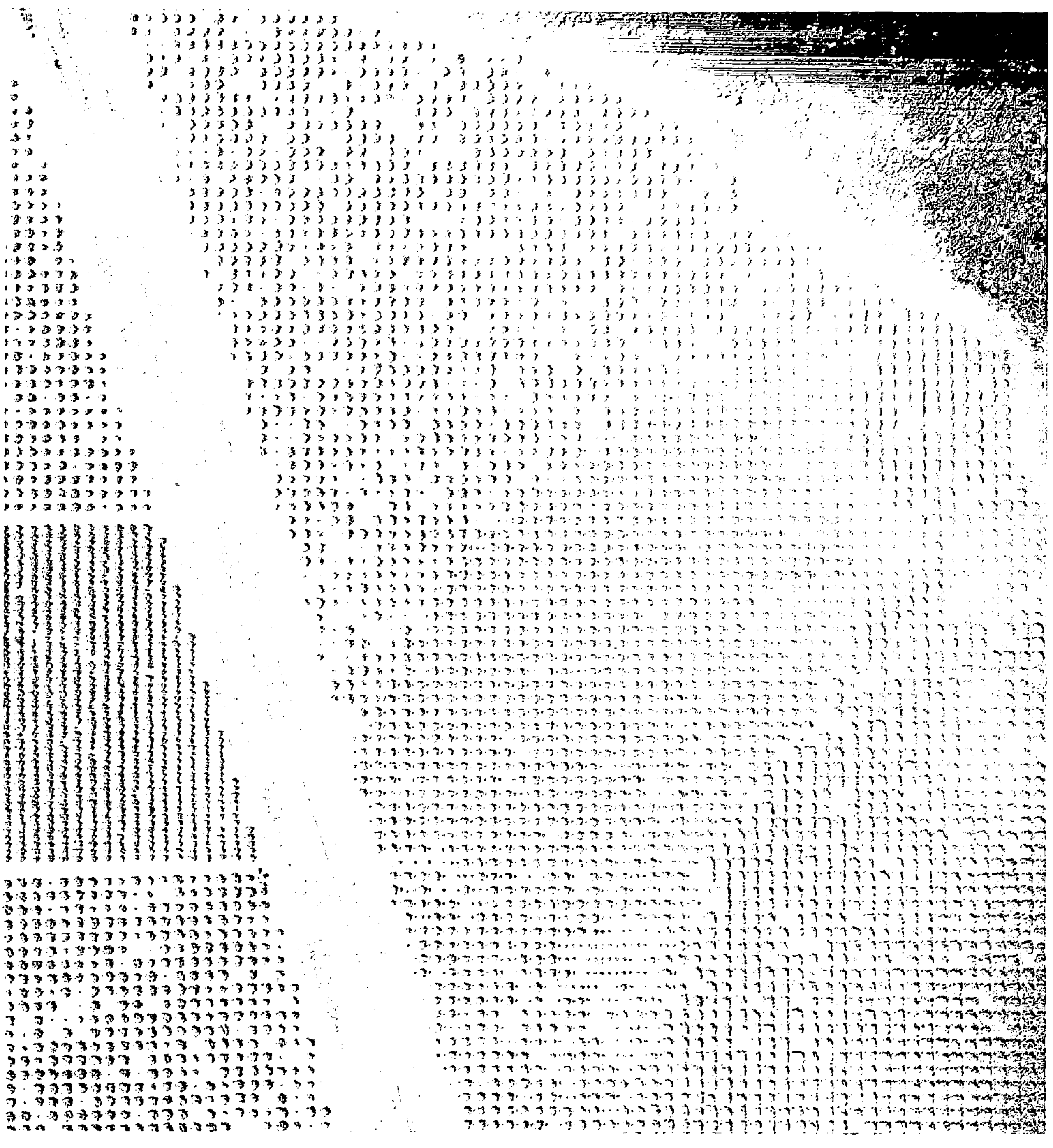


Figure 33. A Polk County grove with a blue cell overlay. (A spring (April 6, 1978) aerial CIR photograph of a grove in Polk County, Florida, with a grid/cell system super-imposed over the photograph and an overlay with a cell cut out to focus on one specific cell of the grove.)

COMPUTER PRINTOUT SYMBOL	
1	FL 802
2	04/06/78
3	14
4	102111Y1
5	010M1010
6	22100011
7	MY130M1M
8	M110133R
9	020YR0YR
10	010100MM
11	00Y0000M
12	−1
13	END

HAND WRITTEN SYMBOL

1	●	2	1	1	1	⊢⊣	1
●	1	●	Λ	1	●	1	●
2	2	1	●	●	●	1	1
Λ	⊢⊣	1	3	●	Λ	1	Λ
Λ	1	1	●	1	3	3	R
●	2	●	⊢⊣	R	●	⊢⊣	R
●	1	●	1	●	●	Λ	Λ
●	●	⊢⊣	●	●	●	●	Λ

COMPUTER	TRANSLATION	WRITTEN
Y	YOUNG TREE	⊢⊣
M	MEDIUM TREE	Λ
R	REPLACEMENT TREE	R
X	MISSING TREE	X
0	HEALTHY TREE	●
1	SLIGHT DECLINE	1
2	MODERATE DECLINE	2
3	SEVERE DECLINE	3
4	DEAD TREE	4

Figure 34. A comparison of hand written and computer symbols. (A comparison of computer printouts, photo interpretations, and field verifications showing the equivalent meanings.)

enhancement techniques, but its application to ACIMS has not been successful to date. Some success has been obtained by utilizing expensive image analysis systems in photo interpreting an ACIR transparency of a peach orchard on light-colored soil without patches of grass or weeds. Use of multispectral scanners (MSS) and image systems is considerably more expensive than the ACIR photography system described in this handbook. It is believed that it will be some time before automated electronic imagery analysis is used in citrus grove management.

DATA PRODUCTS

The final subject that must be discussed in the application of ACIR photography to citriculture is the type of data products that can be produced and how an individual can use these products.

GROVE STATUS REPORTS

Complete tree condition reports may be prepared from manual processes and pseudo-grove maps prepared from photo interpretation as precursors for complete block, bed, or cell analysis. It is possible to compile a block-by-block analysis and present the complete report in tabular form where the total classification of tree conditions (skips, diseased, replants, healthy, total number of spaces, and percent of healthy trees) is reported (Figure 35). This information is valuable to production managers to:

1. Have an accurate number of trees to order for replacement next year based on the number of missing trees (skips)

2. Order sufficient number of trees for replacement 2 years from date of photography (diseased trees)

3. Have a better idea of fruit production from each bed/cell

4. Know which beds or cells have a greater number of diseased trees that may warrant action

5. Associate other parameters with the counts obtained

6. Know if replanted trees are dying, and at what rate (with successive photography)

7. Associate a desirable parameter (rapid tree growth) to a specific source of budwood

8. Accurately compare different horticulture practices (hedging) or a different rate of tree growth due to various rates or types of fertilizers

9. Know the actual grove acreage in production, plus non-productive areas due to low, wet, or poor soil areas.

BLOCKS	1	2	3	4	5	6	7	8	9	10
SKIPS	48	1973	320	1075	1642	179	449	802	257	105
DISEASED	91	2779	1411	2177	3281	514	2628	2179	273	2868
REPLANTS	3	2	2557	1637	354	3	1197	1658	5	2171
HEALTHY	1556	3789	6360	6199	5160	2296	6376	6581	10685	5608
TOTAL SPACES	1698	8543	10648	11088	10437	2992	10650	11220	11220	10710
% HEALTHY	91.6	44.3	59.7	55.9	49.4	76.7	59.9	58.6	95.2	52.4

BLOCKS	11	12	13	14	15	16	17	18	19	20
SKIPS	52	112	441	188	185	800	96	966	1256	113
DISEASED	624	466	2846	373	2580	2610	484	153	2635	2127
REPLANTS	1	34	44	4	4	0	0	0	7	13
HEALTHY	2262	3664	7127	10523	8491	7300	4180	3641	6812	8967
TOTAL SPACES	2939	4276	10458	11088	11260	10710	4760	4760	10710	11220
% HEALTHY	77.0	85.7	68.1	94.9	75.4	68.2	87.8	76.5	63.6	79.9

BLOCKS	21	22	23	24	25	26	27	28	29	30
SKIPS	153	898	885	1780	2651	183	6610	479	6827	542
DISEASED	2231	1908	125	42	1589	4088	10	3321	737	4
REPLANTS	2	3	0	0	3	14	49	8	694	1
HEALTHY	8834	7911	3750	1833	6467	6935	3651	3738	4176	964
TOTAL SPACES	11220	10720	4760	3655	10710	11220	10320	7546	12434	2511
% HEALTHY	78.7	73.8	78.8	50.1	60.4	61.8	35.4	49.5	33.6	39.4

TOTAL SPACES	256,483

Figure 35. Hand processing work form. (An example of a form used for hand processing of a grove in Martin County, Florida, showing the block-by-block count of trees including skips (missing trees), diseased, healthy, replants, and a percent of healthy trees with regard to total spaces.)

COMPUTER PRINTOUTS

The use of minicomputers, like the General Automation SPC 16/65 or microprocessors such as an Apple II, will enable users to have greater versatility in manipulating the results of photo interpretation. It will be possible to interrogate the minicomputer/microprocessor bed-by-bed, cell-by-cell, or in any combination desired, obtaining not only the totals of trees per classification, but their exact location per row and tree, as can be seen in Figure 36. Crop production computer printouts could be readily made by associating tree canopy size with past production estimates and other factors for individual groves (Figure 37).

SITE 58 FLIGHT LINE 802 04/06/78

TREES WITH MODERATE DECLINE			TREES WITH SEVERE DECLINE		
ROW	TREE	– – @ – – – – –	ROW	TREE	– – – – – – – – –
9	27	– – – – – – – – –	4	4	– – – – – – – – –
11	25	@ @ – – – – – – –	5	6	– – – – – – – – –
11	26	– – – – – – – – –	5	7	– – @ – – – – – –
14	26	– – – – – – – – –	END		– – – – – – @ @ –
		– @ – – – – – – –			– – – – – – – – –
		– – – – – – – – –			– – – – – – – – –
		– – – – – – – – –			– – – – – – – – –

SITE 58 FLIGHT LINE 802 04/06/78

CATEGORY	TOTAL
YOUNG	5
MEDIUM	8
REPLACEMENTS	3
MISSING	5
HEALTHY	23
SLIGHT DECLINE	13
MODERATE DECLINE	4
SEVERE DECLINE	3
DEAD	0

Figure 36. Examples of computer printouts of tree conditions. (Examples of computer printouts of tree conditions and location by row and tree number in Cells 7 and 8, and the total number of trees in the grove by categories of tree condition. (Polk County, Site 58, Flight Line 802 of April 6, 1978.)

TREE CONDITION

HEALTHY TREES. . . . . .23 TREES X 10 BOXES EACH = 230 BOXES

```
_ * _ _ _ _ _ _
* _ * _ _ * _ *
_ _ _ _ * * * _
_ _ _ _ * _ _ _
_ _ _ * _ _ _ _
* _ * _ _ * _ _
* _ * _ * * _ _
* * _ * * * * _
```

ROW	TREE	ROW	TREE	ROW	TREE
1	2	4	5	7	6
2	1	5	4	8	1
2	3	6	1	8	2
2	6	6	3	8	4
2	8	6	6	8	5
3	4	7	1	8	6
3	5	7	3	8	7
3	6	7	5		

MEDIUM TREES . . . . .8 TREES X 6 BOXES EACH = 48 BOXES

```
_ _ _ _ _ _ _ _
_ _ _ * _ _ _ _
_ _ _ _ _ _ _ _
* _ _ _ _ * _ *
* _ _ _ _ _ _ _
_ _ _ _ _ _ _ _
_ _ _ _ _ _ * *
_ _ _ _ _ _ _ *
```

ROW	TREE
2	4
4	1
4	6
4	8
5	1
7	7
7	8
8	8

YOUNG TREES. . . . . .5 TREES X 3 BOXES EACH = 15 BOXES

```
_ _ _ _ _ _ * _
_ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _
_ * _ _ _ _ _ _
_ _ _ _ _ _ _ _
_ _ _ * _ _ * _
_ _ _ _ _ _ _ _
_ _ * _ _ _ _ _
```

ROW	TREE
1	7
4	2
6	4
6	7
8	3

TOTAL ESTIMATED PRODUCTION = 293 BOXES

AVERAGE ESTIMATED YIELD		
	HEALTHY TREES	10 BOXES FRUIT
	MEDIUM TREES	6 BOXES FRUIT
	YOUNG TREES	3 BOXES FRUIT

Figure 37. Example of crop production forecast. (Example of crop production forecast that may be prepared from photo interpretation of tree size in a specific cell (Polk County grove, Site 58, Flight Line 802 of April 6, 1978.)

APPENDIX

Information contained in this appendix is intended for those individuals who desire additional information on aerial photography and its uses. Other paragraphs are also included to illustrate the relationship between aerial photography and remote sensing as well as describe the various principles and concepts involved in remote sensing.

AERIAL PHOTOGRAPHY

Aerial photography is a combination of the processes of observation (reconnaissance or scouting) from the air and recording events on film. The principal advantage of aerial observation is that it gives an overview of the desired target or field in contrast to limited viewing from the ground (ref. 1). Secondary advantages are the establishment of permanent records of the surveillance and the ability of the user to select any specific area for additional viewing.

Throughout the history of agricultural research, observations of agricultural events and phenomena have been carried out and recorded by manual, mechanical, and electronic means. A great deal of these observations have been made without contact with the object. Observing a particular event or object without making contact is a way of acquiring remotely sensed data. Remotely sensed data can be acquired by observing through optical systems, telescopes, binoculars, theodolites, cameras, and electronic systems. With the advent of photography (daguerrotype) in 1839 (ref. 15) it was but a short time before it was applied to making topographic sketches in 1840. In 1849, Colonel Aime Lausedat, French Corps of Engineers, began the first program to prove the advantage of making photographic maps from balloons (ref. 15). Progress was slow but captive balloons were used as photographic platforms by 1858, and in 1871, the advent of sensitized emulsions greatly accelerated balloon photography. Although balloons were used in the U.S. Civil War, no records exist of balloon photography in the Army Archives. Both kites and balloons continued to be used as platforms for aerial photographs, but because they were unstable the resulting photographs were neither accurate nor dependable. The development of a reliable aircraft by the Wright brothers produced the stable platform needed for aerial photography, and in fact, the first recorded aerial photographs were taken by Wilbur Wright on April 24, 1909. The use of photography for accurate mapping from an aircraft was first reported by a Captain Tardivo at the 1913 meeting of the International Society of Photogrammetry. The use of aerial photography from aircraft for military surveillance was slowly accepted in World War I, but after its value was established, massive aerial photography of all the battle fields was carried out by the Allies and the Germans. French aerial photographic units printed as many as 10,000 prints in one night during an offensive. The American Expeditionary Forces produced 54,000 prints in 4 days. A similar increase in the use of aerial photography occured during World War II when a great stimulus was given to the development of films, camera systems, and photo interpreters by the needs of military intelligence. Improvements in films resulted in the development by the Eastman Kodak Company, in 1943, of a false-color CIR film for the detection of camouflaged installations. The CIR film possesses a sensitivity in the chlorophyll-dip spectral region so that it detects a high contrast between camouflage and natural backgrounds. While it has been improved periodically, it still retains its basic wide-band spectral sensitivity (Figure A-1). Modifications in color balance producing a wide variation of hues of foliage, have increased the film's usefulness in agricultural applications (ref. 16). The first commercial film released was numbered 8443, designed for hand processing. Some time ago a new type Kodak Aerochrome, No. 2443, was developed for machine processing. The new No. 2443 can be processed by hand, but a number of steps need to be modified. Hand processing information can be obtained from Mr. William Hart, U.S. Department of Agriculture (USDA), Science and Education Administration (SEA-AR) 509 4th Street, P. O. Box 267, Weslaco, Texas, 78596. As mentioned before, the color balance of the film shifts considerably with different batches and is greatly affected by its dimensional stability. The additional sensitivity of film 2443 to detect near-infrared reflectance, 0.2 micron (Figure A-1) beyond the sensitivity of normal color film (Figure A-2), permits the detection of plants in stress, since stressed plants have reduced reflectance in the 0.8 micron to 0.9 micron wavelength. The added sensitivity of 0.2 micron in the near-infrared region of the spectrum greatly improves the ability of film 2443 to detect stressed trees, with wilting or lost leaves in the top of the canopy.

The advantage of ACIR film in the detection of diseased trees prior to ground observations is in reality the combination of the following two factors, the sensitivity of 0.2 micron of CIR and the clearly wilting of foliage in the tree crowns.

CIR film was used during World War II to discriminate between healthy vegetation and camouflage materials. After the war, it was used by Colwell (refs. 5 and 6) in forestry and agriculture to detect health and diseases of cereal crops. Others quickly followed and tested CIR on a variety of crops such as potatoes (ref. 12), vegetables (refs. 2 and 17), and citrus (ref. 14). Gerald Norman formerly of the Division of Plant Industry, Florida State Department of Agriculture, Gainesville, Florida, pioneered the use of CIR in Florida and detected a number of diseases, insects, and nematode problems with oblique ACIR photography. In the past 5 to 10 years, many aerial photographers in other states have begun to use oblique ACIR photography to pinpoint problem areas of stress, disease, insects, nematodes, or other causes. The systematic use of vertical ACIR to locate problem areas using a 12-inch focal length lens camera, was developed at Weslaco, Texas, by Hart et al. (refs. 8 and 9), and in Israel by Hochbar (ref. 11); however, they did not report a mapping technique involving the use of data collection, storage, and analysis systems. In East Germany, Wolff (ref. 18), did considerable work in mapping and detection problems in orchards with B&W film, but barely mentioned any recording or data analysis systems. A great deal of remote sensing experiments have been carried out to date, but it appears that the agricultural community has not yet become fully aware of its potential benefits. There is a great gap in understanding how it is done, the limitations, costs, and benefits derived from ACIR photography.

REMOTE SENSING

The development of electronic surveillance in the late 1950's and 1960's, that used magnetic tape for gathering data instead of photographic film, resulted in the formation of a new field of endeavor called remote sensing. The term was coined by Evelyn Pruitt (ref. 15) in 1960, to include all disciplines involved in data gathering not requiring direct contact with the objects or phenomena under investigation. It can best be defined as the surveillance or monitoring of events which can be documented by photographic, electronic, or hybrid photo-electronic systems. It involves the manipulation of remote sensing systems and knowledge of the electromagnetic spectrum and its component energy parts and their role in radiance, reflectance, absorption, and emission.

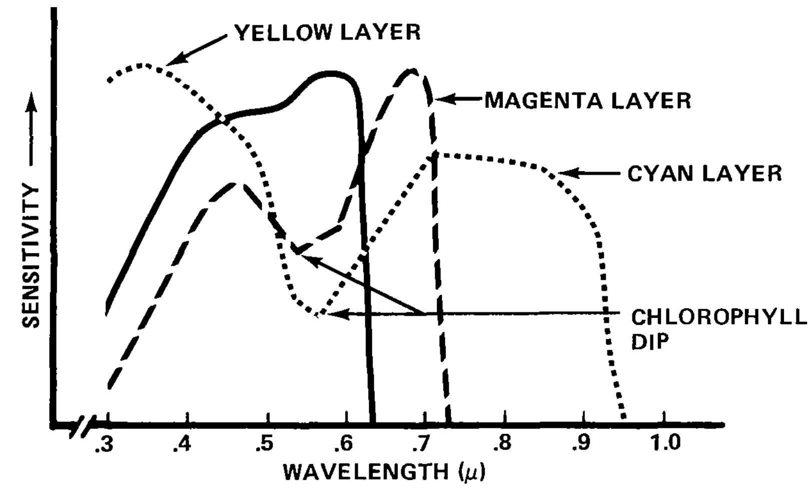


Figure A-1. Sensitivity of color infrared film and wavelengths. (Sensitivity of color infrared film Eastman Kodak No. 2443 showing the location of the chlorophyll dip at various wavelengths in microns (μ) between 0.51 and 0.62 micron.)

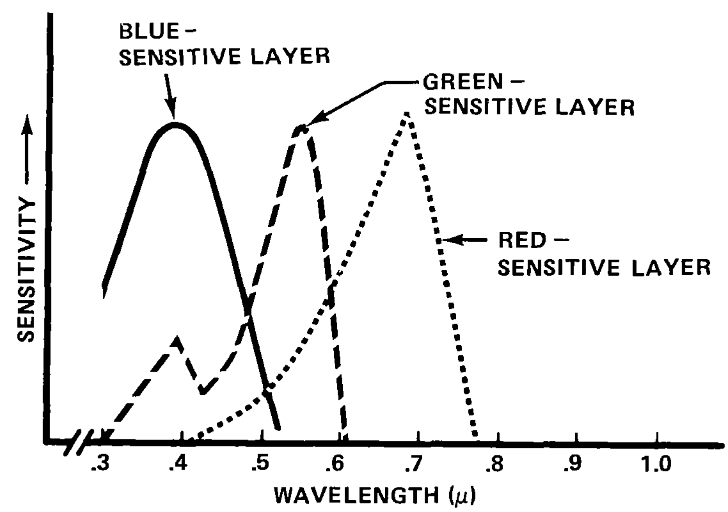


Figure A-2. Sensitivity of normal Ektachrome color film and wavelengths. (Sensitivity of typical normal color film at various wavelengths in microns (μ).)

There are advantages to different types of photographic and electronic systems or their hybrid combinations. Prior to selecting a system, it is necessary to gather and analyze all parameters involved in a study to determine the tradeoff necessary in the use of a specific system or a combination that will yield maximum benefits at minimal cost.

The use of electronic systems has been useful in developing modeling procedures for predicting the effects of road, highway, and bridge building on urban sprawl (ref.15). Potential uses of remote sensing are many and among these useful to agriculture are: the National Weather Service's weather satellites to detect temperature profiles (which may then be associated with insect or disease developmental stages), the direct detection of crop damage with photographic (color infrared) film, electronic (MSS and thermal scanner) systems, and NASA's Landsat satellite in crop estimates.

A brief overview of the fundamental principles and electronic systems involved in remote sensing has been prepared in the following paragraphs to introduce these various concepts to persons unfamiliar with this new technology. The most important concept involved is that of electromagnetic radiation.

Electromagnetic Radiation

Remote sensing is the gathering of information from distances which involves the collection or transfer of some form of radiant energy. The three commonly recognized forms of energy transfer are radiation, convection, and conduction. The only form of energy that can be transferred across free space or through a medium such as air is radiation. Radiation is generated when an electrical charge is accelerated. In a simplified form this means that when an electron (a part of an atom) is forced to change position within an atom by an outside occurence, the position change results in acceleration and gives off radiation as a result. The radiant energy emitted is called electromagnetic energy, having both electric and magnetic properties. Different types of radiated energy can be distinguished by their wavelengths and their frequency characteristics. There is an enormous range of radiation categories possible, due to the many possible variations of conditions in the universe. These variations display wavelength differences varying from hundreds of kilometers down to tenths of microns. The total array of varieties of electromagnetic energy between the two extremes is called the electromagnetic spectrum (EMS). It is commonly thought that the spectrum is divided into regions by wavelength dimensions. Wavelength is the distance between adjoining crests, while frequency is the number of crests passing through a given point during a specific time. Since electromagnetic frequencies, unlike ocean waves, travel at the same speed, the greater the wavelength the lower the frequency (Figure A-3). The visible part of the spectrum is very small representing electromagnetic energy with wavelengths ranging from less than 0.4 micron to nearly 0.8 micron (Figure A-3). The relationship of metric units used to measure the EMS is:

Micron (μ)	=	10^{-6} meters
Micrometer (μm)	=	10^{-6} meters
Nanometer (nm)	=	10^{-9} meters
Angstrom (Å)	=	10^{-10} meters.

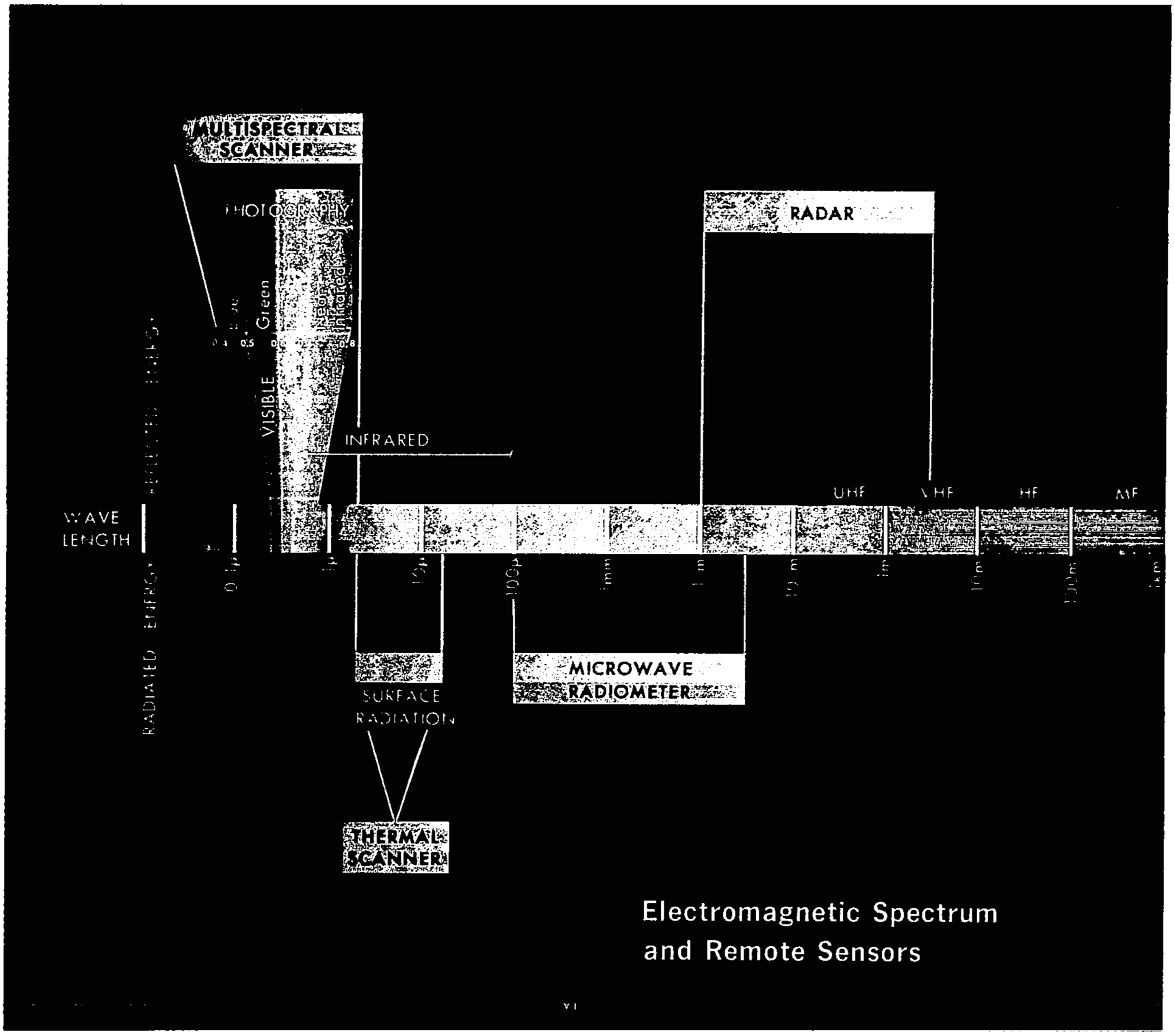


Figure A-3. A schematic diagram of the electromagnetic spectrum (reflected and radiated energy) showing the wavelengths of the visible part, the infrared portion, and the ranges of detection of photographic and electronic sensors (multispectral and thermal scanner, microwave radiometer and radar).

Electromagnetic energy with wavelengths near the visible light of 0.8 micron to 1.4 microns is called the near infrared. Most ACIR film is sensitive from 0.7 micron to 0.9 micron. Electronic scanners range in detection of electromagnetic energy from the visible region through the infrared region (0.7 micron to 100 microns). The earth's atmosphere absorbs some of the energy in the infrared regions preventing transmissions in some bands. There are two bands of the infrared region, 3.5 microns to 5.5 microns and 8 microns to 14 microns, that are not completely affected by the atmosphere and are greatly used for thermal energy detection.

Sensor Systems

Comprehension of the various types of sensor systems makes it possible to understand what systems are feasible and may be available in the future and relate them to systems in current use. Remote sensors are divided into three basic systems: photo-optical, electro-optical, and microwave. These systems are further classified as passive or active. Passive systems receive energy only, while active systems beam their own signals to a target and record the reflected energy.

Photo-Optical Systems (Cameras) - Camera systems can record information on different types of formats (size of film) over the visible spectrum or in separate bands (multispectral) by the use of filters and many lenses. The upper limits of sensitivity are presented in Figure A-4.

Electro-Optical Systems - These systems can record spectral information over a much wider range than cameras; however, the spatial resolution of these sensors does not permit the size of areas to be measured as accurately as with photographic images. Two electro-optical systems used experimentally at KSC in cooperative work with IFAS on the application of remote sensing to citriculture were the Telespectroradiometer (TSR) and the MSS.

Telespectroradiometer - The TSR used by KSC/IFAS has a slightly wider sensing capability than CIR film (Figure A-4). It scans the EMS every 12.5 microns from 0.4 micron to 1.0 micron, after 1.0 micron it scans every 25 microns.

Multispectral Scanner - MSS is an example of passive systems. The typical MSS uses one optical scanning mirror to record the same scene from 12 to 24 different wavelength bands, ranging from ultraviolet to the far infrared. The Daedulus MSS used at KSC has upper limits of 1.14 microns (Figure A-4). The different bands and wavelengths used by the scanner are:

Band	Microns
1	0.38 - 0.42
2	0.42 - 0.45
3	0.45 - 0.50
4	0.50 - 0.55
5	0.55 - 0.60
6	0.60 - 0.65

7	0.65 - 0.69	
8	0.70 - 0.80	
9	0.80 - 0.90	
10	0.90 - 1.10	
11	8.00 - 14	Far Infrared Head

A prism breaks the energy from the scanning mirror and directs it to individual semiconductors (detectors). The energy from each detector is amplified and recorded on separate channels of a magnetic tape. Data tapes are processed by high-speed computers using programs based on a series of algorithms. Operators can select specific scenes to train the computer to recognize patterns. The computer can then rapidly classify entire tapes without difficulty.

Microwave systems - Microwave systems are active systems and send pulses or coherent beams of light and measure signals returned from specific targets.

Side-Looking Radar - This is a typical active system which sends microwave pulses from an antenna mounted on the side of an aircraft. The signals are partially reflected by the target. The reflected waves, modified by the scene or object they encounter, are received by the radar system. These signals are amplified and recorded on magnetic tape.

Laser Systems - This is another type of active system that transmits a coherent beam of light to the subject of interest and records the wavelength phase change of the reflected beam. Laser systems can sense distance accurately enough to measure the relative tallness of trees. Laser beams can damage human eyes and can only be used in uninhabited areas.

Types of Platforms

The most common types of platforms currently used in remote sensing are aircraft and satellites. These two types of platforms provide greater stability and reliability than other platforms such as balloons and kites. Three kinds of sensor systems can be operated from aircraft and satellites; photographic, electronic, and hybrid combinations. In general, photography is used more frequently on airborne platforms while electronic systems are more prevalent on satellite platforms.

Airborne Systems - The advantages of airborne systems are the great flexibility to initiate or terminate a mission at will with little inconvenience, and the capability to handle both film and electronic systems simultaneously and service them when the aircraft returns to base.

Satellite Systems - Satellite systems provide a synoptic overview of regional relationships and allow for repetitive coverage of the Earth within periods of time that cannot compare with coverage from aircraft platforms. Photography or imagery can be obtained from various parts of continents under similar conditions. There are two kinds of satellites, automatic and manned. Automatic satellites may have specific purposes such as the collection of weather data (Nimbus, TIROS, and GOES) or the gathering of earth resources information (Landsat 1, 2, and 3). Manned satellite platforms

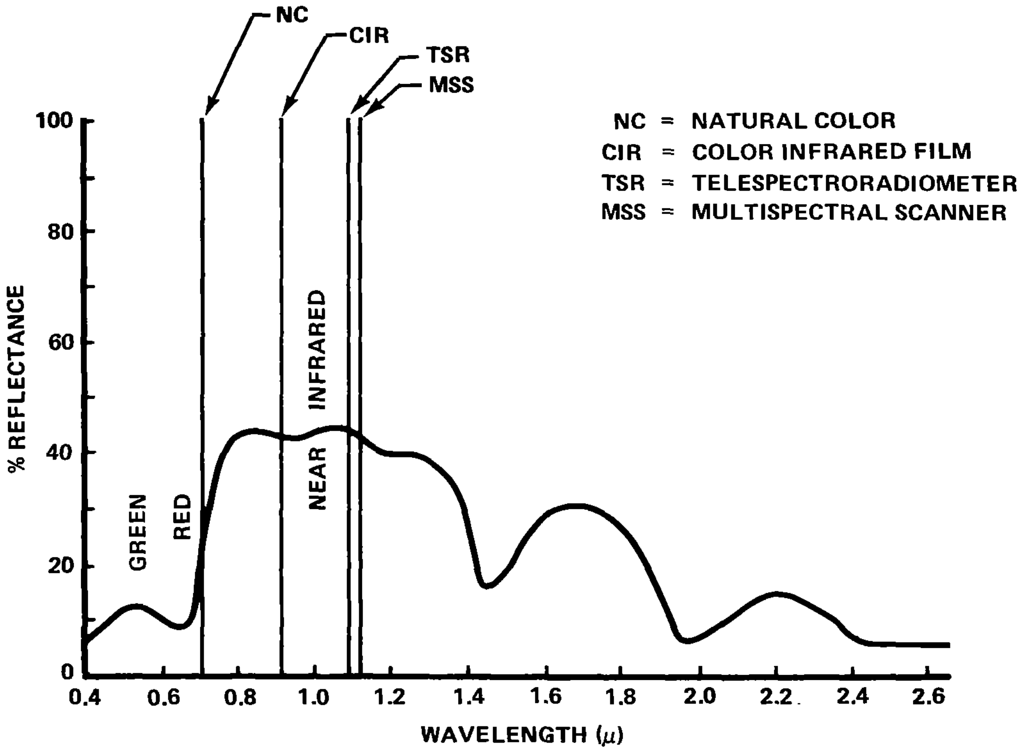


Figure A-4. Upper limits of sensitivity of photographic and electronic sensors. (Identification of absorption bands typically affecting the reflectance of green vegetation, with the lines showing the highest wavelength to which natural color (NC), color infrared film (CIR), telespectroradiometer (TSR), and multispectral scanner (MSS) are sensitive, or able to measure.)

have been primarily experimental rather than operational (Skylab), and are much more expensive to operate and maintain because of the required life support systems.

Weather Satellites - Data from these satellites is collected mostly by visible systems (Vidicon cameras), infrared radiometers, and sounding spectrometers. The more familiar data collected is the series of photographic loops of film from infrared scanners indicating cloud formations and movement of fronts shown on commercial television stations. The most familiar weather satellites are Nimbus, TIROS, and GOES.

Landsat - Three earth resources satellites (formally called ERTS) have been launched; Landsat 1 in 1972, Landsat 2 in 1975, and Landsat 3 in 1978. A fourth satellite may be launched in 1981. Prior to launching, earth resources satellites (ERTS) are referred to by letters, i.e. A, B, C, and D; however, after they are operational in orbit the letters are changed to numbers (Landsat 1, 2, 3, and 4). The primary mission of the Landsat satellites is to gather large volumes of earth resources data that is useful in resources management.

Landsat flies in a circular orbit at an altitude of approximately 570 miles. It completes 14 orbits in 24 hours, and scans the entire earth, except for the poles, once every 18 days. Its orbit is termed solar synchronous, which means that it maintains constant time with respect to the sun.

Sensors on board the satellite send data to receiving stations in Alaska, California, and Maryland. This data are converted to electromagnetic imagery at the Data Processing Facility at Goddard Space Flight Center, then sent to the EROS Data Center in Sioux Falls, South Dakota for storage. The general public, business, industry, and government have access to the Landsat imagery stored at the EROS Data Center.

Three data acquisitions systems are carried on Landsat, the MSS, a Return Beam Vidicon (RBV) camera, and a Data Collection System (DCS) to relay data from ground-based data collection platforms. A wideband video tape recorded augments the system.

The MSS is the primary sensor system. The Landsat scenes are 100 nm x 100 nm in four spectral bands: One green, one red, and two near infrared. The red band emphasizes variations in water (sediments, pollution, reefs, and shoals) and topography. The green band distinguishes cultural features more readily, for example, cities, industry, and urban sprawl. The two near infrared bands enhance the boundaries between vegetation and water, or landforms and water.

The MSS image itself is built up of 2,340 individual scan lines, in much the same way a television picture is built up; it takes 25 seconds to compile the information for one photograph.

The RBV camera, on the other hand, takes instantaneous pictures and gets better spatial resolution. Sometimes, this type of information is more useful.

As mentioned earlier, the DCS acts as a relay for information on the environment, such as temperature, wind, humidity, or pollution from ground-based data collection platforms. In this manner, ground information and satellite imagery of the same area can be correlated.

Landsat is an earth resources management tool, and one that is tremendously versatile and powerful. It is used regularly for applications to mapping, geology, agriculture, water monitoring, land use evaluation and planning, coastal and marine surveys, and pollution monitoring.

GLOSSARY

absorption:	The process by which radiant energy is absorbed and converted into other forms of energy.
angstroms (Å):	A unit of measurement, 10^{-10}m. One ten-thousandth of a micron.
apochromatic lens:	A camera or microscope lens corrected for color (chromatic) and spherical (astigmatic) aberrations with its focus adjusted to color and color infrared photography. A color corrected lens.
background photography:	Existing or previous photography of a citrus grove to be used for reference in planning a photographic mission.
baseline photography:	The first CIR photographs of a citrus grove; used for grove management.
bloom:	The flowering stage of a tree.
calibration site:	Same as a fundamental test site.
cell:	A basic unit of citrus grove mapping developed for rapid reference to trees--may vary from 8 trees x 8 trees to 16 trees x 16 trees according to tree planting distance.
chroma:	The color dimension on the Munsell scales that correlates most closely with saturation.
coherent:	In the electromagnetic spectrum (EMS) being in phase, so that waves at various points act in unison, as in a laser producing coherent light.
color corrected lens:	A camera lens free from color (chromatic) and spherical (astigmatic) aberrations with its focus adjusted to color and color infrared photography. An apochromatic lens.
detector (radiation):	A device providing an electrical output that is a useful measure of incident radiation broadly divisible into thermal and photo detectors.
diopter:	A unit of measurement of the refractive power of lenses equal to the power of a lens with focal distance of one meter. A 2 diopter lens (2X) has a magnification of 2 diameters.

electromagnetic spectrum (EMS):	The ordered array of electromagnetic radiations extending throughout all wavelengths.
emission:	With respect to electromagnetic radiation (EMR), the process by which a body emits EMR usually as a consequence to its temperature only.
enlargements:	Black and white or color print copies of ACIR transparencies at a larger scale than the negative.
extended test site:	An area of an experiment too large to be representative of a region, yet small enough to be studied in detail.
false color infrared film:	A color film with shifted layers of dye and made sensitive below 0.3 micron to 0.9 micron, 0.2 micron above visibility by the human eye. Colors are partially sensitized chemically to give false colors for better separation.
flight line map:	Indicates the desired lines of flight or the position of the frames taken in an aerial photographic mission.
flush:	A sudden and abundant growth of citrus tree leaves.
focal length:	The distance measured along the optical axis from the optical center of the lens to the critical focus of a very distant object.
focus:	The point at which the rays from a point source of light reunite and cross after passing through a camera lens. In practice, the plane in which a sharp image of any scene is formed.
forward lap:	The overlap of aerial or space photographs or images along the flight line or track of the platform.
frequency:	Number of oscillations per unit of time or number of wavelengths that pass a point per unit of time.
fundamental test site:	Small areas subjected to intensive studies using various types of remote sensors to determine the interaction of reflectance in individual conditions; same as a calibration test site.
holes:	Areas found in canopies of citrus trees with preliminary stages of poor tree condition showing dead areas on twigs.
hot spot:	An elliptical area of bright reflectance occuring 180 degrees from the direction of the sun which causes nearly half of each frame to be overexposed. Photographs taken with a 6-in. focal length lens generally contain the hot spot within the frame, while those taken with a 12-in. focal length lens generally have the hot spot outside the frame. Also referred to as a sun spot.

hue:	That attribute of a color by virtue of which it differs from gray of the same brilliance, and which allows it to be classified as a specific color: red, blue, etc.
large scale photography:	Photography taken from low altitude overflights so that the scale has a small denominator, i.e., 1:500.
laser:	A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal (Light Amplification by Stimulated Emission of Radiation).
light boxes (tables):	Boxes or tables with a translucent top, allowing the passage of flourescent light through a diffusing plastic for better observation of film transparencies.
magnetic tape:	Plastic tape capable of recording signals either in sound or electronic form.
micron (μ):	Micromillimeter (μ), the millionth part of a millimeter, a micrometer all equivalent to 10^{-6}.
multispectral:	In remote sensing, it refers to photographic or scanning in different spectral bands.
nanometer (nm):	A millimicron, the billionth part of a millimeter (10^{-9}).
net gain:	The actual gain (per photograph) in area per frame in a roll of film in the forward overlap, in contrast to the total area of each frame, when considering overlap.
oblique photography:	A photograph taken at an angle less than 90 degress in relation to the horizon. A high-oblique photograph includes the horizon with the field of view and a low-oblique does not.
overflight:	Flight over a specific area to collect data.
overlap:	Area of photograph duplicated in adjacent (either forward or side) photographs expressed as a percentage.
overlays:	Transparent films (mylar, acetate) superimposed over CIR transparencies or enlargements on which photo interpretation data is recorded.
ozalid maps:	Copies or enlargements of aerial photographs copied by a photographic Diazo process resulting in blue-line maps.
parallax:	The apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation.

photogrammetry: The art or science of obtaining reliable measurements by means of photography.

radiance: The accepted term for radiant flux in power units, and not for flux density per solid angle.

reflectance: The ratio of the radiant energy reflected by a body to that incident upon it. The suffix (-ance) implies a property of that particular specific surface.

registration: The matching of an object or point in different or segmented photographs. The perfect match in point location in separate images.

resolution: The finite limit of distinctiveness or (visibility of a specific object) definition measured in lines per millimeter.

return beam vidicon (RBV): A modified vidicon television camera tube, in which the output signal is derived from the depleted electron beam reflected from the tube target. The RBV can be considered a cross between a vidicon and an orthicon. RBV's provide highest resolution TV imagery, and are used in the ERTS (Landsat) series.

scale: The scale of an image is expressed as the ratio of the image size on the photograph to the object's size on the ground. The numerator represents the size on the film, and the denominator indicates the object size on the ground. Example 1:333 means that 1 in. on the film represents 333 ft on the ground.

scanner: Any device that scans, and by this means produces an image.

scouting: Aerial observation: i.e. a term used in pest management for ground surveillance.

semiconductor: A body or substance capable of partially conducting electricity.

sensors: Any device that gathers energy from the EMS and presents it in a form suitable for obtaining information.

sidelap: The area common to two photographs in adjacent flight strips; the amount is expressed as a percentage of the total photo area.

small scale photography: Photography taken from high altitude overflights so that the scale has a large denominator, i.e., 1:60,000.

spectral band: An interval in the EMS defined by two wavelengths, frequencies, or wave numbers.

spectral signature:	The characteristic reflectance properties of an object or similar objects.
stressed:	In reference to citrus trees, less than healthy in an unthrifty condition that may be due to disease or other conditions.
sun angle:	Angle of the sun above the horizon, also sun elevation. Both the quantity (lumes) and quality of light is affected by the sun angle.
sun spot:	The same as hot spot.
vertical photograph:	A photograph taken with the main axis of the lens perpendicular to the object to be photographed.
video tape:	Ferrous oxide coated plastic tape capable of recording electronic signals that reproduce images.
wavelength:	Wavelength = velocity/frequency. The mean differences between maximums (or minimums) of a roughly periodic pattern.
window-overlay:	A system of superimposing a grid system over a transparency and another grid with a small sector removed for image viewing.
vignetting:	The progressive reduction in the cross sectional area of a beam of light passing through a lens as the field angle is increased.

REFERENCES

1. Avery, E. T.: Interpretations of Aerial Photographs. Burgess Publishing Company, Minneapolis, Minnesota. 319 pp, 1968.

2. Blazquez, C. H.: Detection of foliar diseases; diseases of vegetable crops with color infrared photography. Proceedings 3rd Biennial Workshop Aerial Color Photo. 1971:236-245, 1971.

3. Blazquez, C. H.: Citrus grove mapping with colored infrared aerial photography. Proced. Florida State Horticultural Society 91:5-8, 1978.

4. Clegg, R. H.; and Scherz, J. P.: A comparison of 9-in., 70mm and 35mm cameras. Photogrammetric Engineering and Remote Sensing 41:1487-1500, 1975.

5. Colwell, R.N.: Determining the prevalence of certain cereal crop diseases by means of aerial photography. Hilgardia 26:226-286, 1956.

6. Colwell, R. N.: Monitoring earth resources from aircraft and spacecraft. NASA SP-275:1-170, 1971.

7. Hammerschlag, R. S.; Sopstyle, W.: Investigations of remote sensing techniques for early detection of Dutch Elm Disease. Remote Sensing of Earth Resources, University of Tennessee, Vol. 4:357-385, 1975.

8. Hart, W. G.; Ingle, S. J.; Davis, M. R.; and Mangum, C.: Aerial photography with infrared color film as a method of surveying for citrus blackfly. J. Econ. Entomol. 66:190-194, 1973.

9. Hart, W. G.; Ingle, S. J.; and Davis, M. R.: Remote sensing of insect populations attacking citrus. Proc. In. Soc. Citriculture 2:485-487, 1977.

10. Heath, G. R.: Hot spot determination. American Society of Photogrammetric Engineering 34:1205-1214, 1973.

11. Hochbar, R.; Rabid, N.; Alvf, S.; and Oren, Y.: Infrared color photography survey on damaged and degenerated trees. Israel Min. Agriculture. Ext. Bul. 1974. 310:1-10, 1974.

12. Manzer, F. E.; Cooper, G. R.: Aerial photographic methods of potato disease detection. Maine Agriculture Exp. Sta. Bull. 646:1-14, 1967.

13. Murtha, P. A.: A guide to photo interpretation of forest damage in Canada. Can. Forestry Serv. Pub. No. 1292:1-63, 1972.

14. Norman, G. C.; Fritz, N. L.: Infrared photogrphy as an indicator of disease and decline in citrus trees. Proc. Fla. State. Hort. Soc. 78:59-63, 1965.

15. Reeves, R. G.; Anson, A.; and Landen, D.: Manual of Remote Sensing. American Society of Photogrammetry. Washington, D.C. 2144 pp, 1975.

16. Shay, J. R.: Remote sensing with special reference to agriculture and forestry. Nat. Acad. Science. Washington, D.C. 422 pp, 1971.

17. Wallen, V. R.; and Philpotts, L. E.: Detection of bacterial blight of beans by Ektachrome infrared aerial photography. Proc. 2nd. Biennial Workshop. Aerial Color Photo. 69-70, 1969.

18. Wolff, G.: The assessment of intensively worked orchards by aerial photo interpretation. Jena Rev. 21:82-87, 1976.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA RP-1067		

4. Title and Subtitle	5. Report Date
AERIAL COLOR INFRARED PHOTOGRAPHY: APPLICATIONS IN CITRICULTURE	November 1980
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Carlos H. Blazquez and Frank W. Horn, Jr.	TR 43-1
9. Performing Organization Name and Address	10. Work Unit No.
NASA John F. Kennedy Space Center John F. Kennedy Space Center, FL 32899 and University of Florida/Institute of Food and Agriculture Sciences P.O. Box 1088, Lake Alfred, FL 33850	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Reference Publication
National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code NASA KSC PT-STA

15. Supplementary Notes

Carlos H. Blazquez: University of Florida.
Frank W. Horn, Jr.: John F. Kennedy Space Center.

A joint project of the John F. Kennedy Space Center, Advance Planning and Technology Office and the University of Florida/Institute of Food and Agricultural Sciences.

16. Abstract

Aerial color infrared (ACIR) photography is a promising tool for citrus grove management to obtain, interpret, and compile synoptic grove information that will improve decision making. The optimum photographic specifications and operational parameters for ACIR photography in citriculture are described to overcome a sizable gap in communication between citrus growers who could profit from ACIR photography and the aerial photographers who could provide it. The photographic specifications and operational parameters, described in this handbook, were determined in a large ACIR photographic experiment and in a follow-up demonstration with the cooperation of citrus growers and aerial photographers. The following steps were found to result in successful ACIR photographic missions: (1) Grower-aerial photographer planning sessions, (2) Photographic limitations, (3) Horticulture restrictions, (4) Photographic product requirements, (5) Writing of agreement, (6) Execution of mission, and (7) Acceptance of product-compliance with requirements. ACIR photography in the spring gave the best separation between healthy and diseased trees. The best scale for photo interpretation with the use of inexpensive analysis equipment was 1 in. = 333 ft. Photographs taken with a 12-in. focal length lens were far superior to those taken with a 6-in. focal length lens. A cell-unit grid system, with window-overlays for rapid photo interpretation and a black and white enlargement for ground verification, was developed for tree registration. Use of the enlargement in ground surveys reduced the survey time from 25 hours to 2.5 hours. The cell-unit grid system is compatible with computer processing for rapid recording of photo interpreted data, storage, retrieval, and analysis. A mapping system with 99 percent accuracy was developed for fast surveillance of tree vigor and stress.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
Aerial Color Infrared Management System (ACIMS) Aerial Color Infrared photography (ACIR) Base-line and background photography Calibration site Citrus grove management	Color correct lens Damage assessment Flight-line map Focal length Grove grid/cell Remote sensing Sun spot Window overlays	Unclassified - Unlimited Subject Category 43

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	89	A05

*For sale by the National Technical Information Service, Springfield, Virginia 22151

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

THIRD-CLASS BULK RATE

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

U.S.MAIL

10 1 RP,1U,E, 111780 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LABORATORY
ATTN: TECHNICAL LIBRARY (SUL)
KIRTLAND AFB NM 87117

NASA

POSTMASTER: If Undeliverable (Section 1
Postal Manual) Do Not Ret